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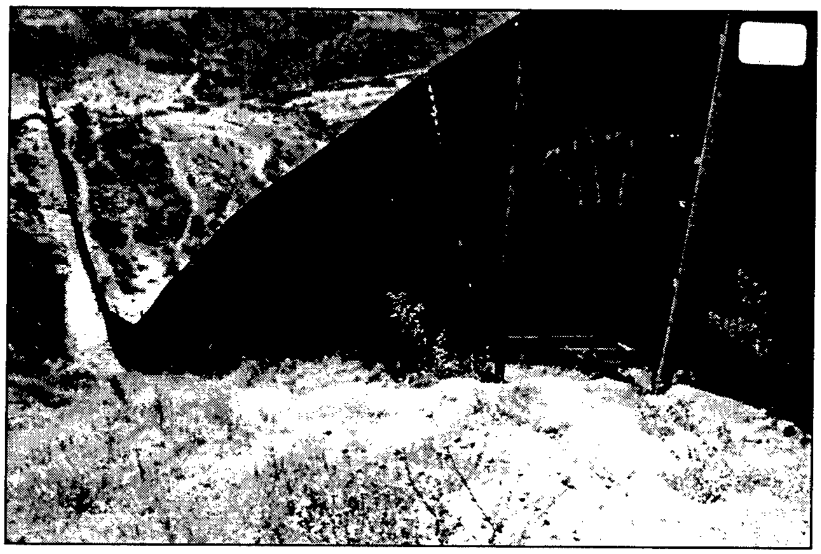
Engineering Life-Cycle Cost Comparison Study of Barrier Fencing Systems

Dr. Charles P. Marsh, Dr. Ellen G. Segan, Brian Temple, and Tod E. Kaspar



The Immigration and Naturalization Service (INS) is responsible for the administration and enforcement of U.S. immigration laws. Enforcement mainly involves apprehending illegal immigrants and assisting with the interdiction of illegal drug smugglers and suspected terrorists. The United States has approximately 6,000 miles of land-based international border. By far the largest problem with illegal immigration occurs along the 2,000 miles of border with Mexico. Along this border, nearly 90 percent of the apprehensions occur along 200 miles distributed near nine major U.S. cities and towns such as San Diego, CA, and El Paso, TX.

Current fencing, where it exists, is often in a severe state of disrepair. To cost effectively increase deterrence against illegal entry, the INS is considering the widespread application of several different fencing systems for these high traffic areas. Little to no detailed engineering-based comparisons have been made for these fencing options so no basis currently exists with which to make an informed decision based on reliability, effectiveness of deterrence, economics, and ability to withstand attack.

This report discusses analyses of several fencing system options that would provide both effective and minimum life-cycle cost service for primary, secondary, and tertiary barrier needs.

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13. ABSTRACT (Maximum 200 words)
The Immigration and Naturalization Service (INS) is responsible for the administration and enforcement of U.S. immigration laws. Enforcement mainly involves apprehending illegal immigrants and assisting with the interdiction of illegal drug smugglers and suspected terrorists. The United States has approximately 6,000 miles of land-based international border. By far the largest problem with illegal immigration occurs along the 2,000 miles of border with Mexico. Along this border, nearly 90 percent of the apprehensions occur along 200 miles distributed near nine major U.S. cities and towns such as San Diego, CA, and El Paso, TX.

Current fencing, where it exists, is often in a severe state of disrepair. To cost effectively increase deterrence against illegal entry, the INS is considering the widespread application of several different fencing systems for these high traffic areas. Little to no detailed engineering-based comparisons have been made for these fencing options so no basis currently exists with which to make an informed decision based on reliability, effectiveness of deterrence, economics, and ability to withstand attack.

This report discusses analyses of several fencing system options that would provide both effective and minimum life-cycle cost service for primary, secondary, and tertiary barrier needs.

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Executive Summary

This engineering life-cycle cost comparison study has examined 10 barrier-fencing systems for use in three related but separate applications at the southern border of the United States. For each application, the detailed performance requirements and primary degradation factors are considered. In the absence of any maintenance records and operational experience with many of the design options, two sets of assumptions were used in each case to define a best and worst case scenario. For the purposes of this study, all designs were presumed to reasonably meet the performance requirements of the application for which they were considered. This approach was taken even though a detailed inspection of an existing landing mat fencing system identified both design and operational problems.

For the primary barrier, located directly at the international border, the landing mat fencing system was found to have the lowest life-cycle cost. For the secondary barrier, the Sandia fencing system resulted in the lowest life-cycle cost. In addition, the 6-ft chain link fencing system was found to have the lowest life cycle cost for the tertiary barrier application. Although these results attempt to account for the effects of terrain, structural vandalism, projected maintenance and repair (M&R) costs and special equipment needs, they should be considered preliminary. For this application, more operational experience is needed to arrive at an optimized and practical solution.

Table ES1. Life-cycle cost comparison summary for the barrier fencing systems considered.

Fencing Type	Construction Cost/Mile ($US) (Optimistic)	Net Present Value After 25 Years / Mile ($US)	
		Best Case Scenario	Worst Case Scenario
PRIMARY FENCE			
Landing Mat	$341,584	$4,725,572	$7,340,098
Pre-Cast Concrete Panels	$630,000	$9,052,258	$10,710,604
Bollard Design - Bare	$1,667,000	$22,150,205	$26,634,191
Bollard Design - Steel Cased	$2,083,750	$27,617,892	$33,202,423
SECONDARY FENCE			
Bollard Design (both)	(same as above)	(same as above)	(same as above)
Sandia Fence	$691,680	$9,731,757	$54,233,802
First DeFence®	$834,240	$11,697,504	$65,167,943
TERTIARY FENCE			
Chain Link - 10 Ft	$55,000	$855,511	$4,809,899
Chain Link - 6 Ft	$44,465	$710,235	$4,001,830
Note: Calculations were performed with the ECONPACK program using a 6.585 percent discount rate, 1997 dollars, and an inflation rate of 3.4 percent.			

Foreword

This study was conducted for the Department of Justice under a Memorandum of Understanding. The project number was COW766011, Immigration and Naturalization Service (INS), Work Unit H87, "Fence and Roads Study." The INS technical monitor was Kevin Jackson.

The work was performed by the Materials Science and Technology Division (FL-M) of the Facilities Technology Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (CERL). The USACERL principal investigator was Dr. Charles P. Marsh. Dr. Ilker R. Adiguzel is Chief, FL-M, and L. Michael Golish is Operations Chief, FL. The USACERL technical editor was Linda L. Wheatley, Technical Information Team.

Dr. Michael J. O'Connor is Director of USACERL.

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1 Introduction

Background

The Immigration and Naturalization Service (INS) is the division of the U.S. Department of Justice responsible for the administration and enforcement of U.S. immigration laws. The enforcement aspect deals mainly with apprehending illegal immigrants, as well as assisting with the interdiction of illegal drug smugglers and suspected terrorists. Of the approximately 6,000 miles of the land-based U.S. international border, approximately 2,000 miles of it borders Mexico. By far the largest problem with illegal immigration occurs along this border. Nearly 90 percent of the apprehensions along the Mexican border occur over 200 miles distributed near nine major U.S. cities and towns such as San Diego, CA, and El Paso, TX (Federation for American Immigration Reform, 1989).

Current fencing is often in a severe state of disrepair, if it exists at all. To cost effectively increase deterrence of illegal entry, the INS is considering the widespread application of several different fencing systems for these high traffic areas. Among these fencing options, little to no detailed engineering-based comparisons have been made. As a result, no basis exists with which to make an informed decision based on reliability, effectiveness of deterrence, economics, and ability to withstand attack.

Objectives

The objective of this analysis was to determine which of several options of fencing systems would provide both effective and minimum life-cycle cost service for each of the three identified barrier needs: primary, secondary, and tertiary.

Approach

Much of this work involved coordination between the INS, the Border Patrol, the U.S. Army Corps of Engineers' San Diego, Fort Worth, and Los Angeles Districts, City of San Diego, CA, State of California, Bureau of Land Management, National Guard, U.S. Fish & Wildlife Service, U.S. Attorney's Office, and USACERL (see Appendix A for a list of participants). Participation in the ongoing project along the 14 miles of border at San Diego served to better define the larger problem even as various designs evolved. To characterize both the intended service environment and the current maintenance procedures, a detailed engineering inspection of the existing primary barrier (Appendix B) was performed. Based on these findings, life-cycle cost analyses of the various options were performed using the ECONPACK software package with a bounded approach. In the absence of any maintenance records and operational experience with most of the design options, two sets of assumptions were used for each system in order to define a best and worst case scenario.

Scope

This report documents an engineering comparison study for a number of barrier fence designs. Incorporation of various practical aspects of the context in which a fence would serve as part of an overall deterrence strategy was attempted. Given the lack of information on many of the necessary inputs, and further, how some inputs might evolve over time (i.e., the means, degree, and location of active and purposeful degradation), this study must necessarily be considered preliminary.

Mode of Technology Transfer

This study is intended to assist the INS in making well-informed engineering-based decisions concerning their infrastructure management needs.

Units of Weight and Measure

U.S. standard units of measure are used throughout this report. A table of conversion factors for Standard International (SI) units is provided below.

SI conversion factors		
1 ft	=	0.305 m
1 in.	=	2.54 cm
1 lb	=	0.453 kg
1 mi	=	1.61 km
1 yd	=	0.9144 m

2 Requirements and Degradation Factors

Performance Requirements

A fence or barrier is used to deter illegal immigration and drug smuggling at locations other than controlled points of entry. To assist the Border Patrol in performing their duties, a three-fence system comprising primary, secondary, and tertiary barriers is being developed for areas of high population density along the southern border. The primary fence is positioned directly at the geographical international border with the secondary and tertiary barriers parallel and fixed distances north of the primary. All three barriers are required to be reasonably safe for those individuals attempting to traverse them. In particular, this requirement means that razor wire, barbed wire, and sharp edges are disallowed. Structural integrity also needs to be assured given that wind loading and other intermittent dynamic forces could cause a dangerous collapse. For this reason, some less humane options such as electrified fencing were not considered suitable for consideration or inclusion in this study.

The fencing that was considered consisted of two major types. The first type consists of an upright support frame with various in-fill options. The frame is various steel supports set in concrete anchors throughout, and the in-fill is, alternatively, steel panels, reinforced concrete panels, and steel mesh (e.g., chain link, expanded metal, and fine mesh). The second broad category of fencing might consist of posts, pickets, or palisades. The essential feature of this fence type is a repeated vertical element set sufficiently close together so as to be impassable.

For all fence systems studied, a number of issues relating to actual field construction were considered. The effect of steep terrain was assumed to add additional costs both for material transport and construction. For some specific designs, sufficiently steep terrain could severely hamper or even prevent construction (e.g., the inability to position a large crane). Where applicable, the need for any specialized equipment is noted. In addition, if an above average or specialized skill level is needed by one or more construction workers to reliably install a fence design, this also is noted.

The individual requirements for the three-fence systems were assumed to vary in severity with the most restrictive needs existing at the border itself. The primary barrier should effectively:

- prevent vehicle drive-through
- deter climbing over to the North
- deter tunneling under (no time limit)
- be resistant to acts of structural vandalism, or active degradation (no time limit)
- prevent easy return to the South (for Border Patrol operational needs).

The secondary barrier should effectively:

- prevent climbing over to the North
- deter tunneling under (within 1 hour)
- be resistant to active degradation (within 1 hour).

The tertiary barrier has the least restrictive requirements of effectively deterring climbing over to the North.

Degradation Factors

The various potential modes of fence degradation are assumed to be classified as either active or passive. Passive degradation consists of all environmental effects that occur without any human assistance. These effects would include the results of corrosion, local micro-climate (i.e., proximity to the sea), wind, morning dew, temperature, rain, flash flooding, and long-term erosion. In contrast, active degradation includes all acts of vandalism directed at a fence, which typically involves the use of tools. Ramming the primary barrier with a motorized vehicle is one of the more overt examples of active degradation. However, the use of hacksaws, cutting torches, shovels, hammers, picks, fire, crowbars, and all other implements also fall into this category.

Given the relative severity and economic impact of active compared to passive degradation, only reasonable extremes of active degradation were considered in this analysis. An implicit requirement for all the design options is the ability to withstand passive degradation. Given the other needs and requirements, this ability proved to offer no additional constraint. It is worth noting that the nature of active degradation tends to be opportunistic so that vandalism is typically concentrated at weak points in the barrier. In addition, the vandalism often has an innovative and adaptive element to it. As a result any list of expected countermeasures for a specific barrier design cannot be completed without some construction and operational field experience.

3 Description of Barrier Fencing

Primary Barriers

Landing Mat

This fence is composed of surplus carbon steel landing mats, 12-ft long, 20-in. wide, 1/4-in. thick (dimensions approximate). For each mile, 3,080 panels are used. Landing mats are welded to 3 to 6 in. (various) steel well-casing pipes buried to a depth of 8 ft every 6 ft along the fence. Landing mats are stored surplus and are available without cost to the project. Currently, roughly 14 miles of this fence is installed along the border in the San Diego District, with enough panels in surplus to construct an additional 60 to 90 miles of fencing. Some areas also include an anti-tunneling measure to prevent entry underneath the fence. The measure is subsurface steel panels (often damaged landing mat unsuitable for fencing) set in a concrete matrix along the fence line to a depth of 2 to 3 ft. The U.S. Army Reserves are responsible for the construction of new fence, and the U.S. Border Patrol is responsible for its M&R. Terrain/topographic concerns are minimized because of ease of installation.

The landing mat fence (shown in Figure 1) is one of the few designs where significant long-term experience has been gained for its application. Although its installation was an impressive effort in response to the mission needs of the Border Patrol, the benefit of functional experience offers some lessons learned. An initial lack of detailed design, construction procedures, and performance requirements has resulted in problems. These problems include:

- inadequate footings for the terrain, loads, and soil conditions involved
- lack of provision for thermal expansion
- inadequate corrosion protection
- lack of dig-under prevention
- inadequate resistance to mechanical attack
- inadequate barrier to quick re-entry into Mexico to avoid apprehension (a Border Patrol operational requirement).

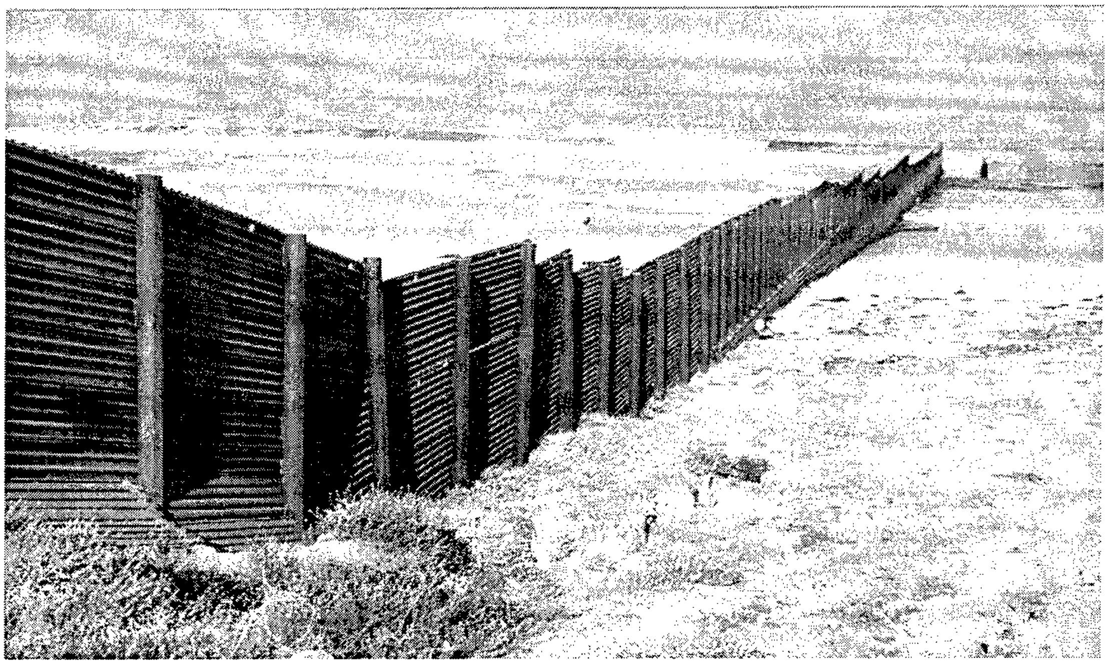

Figure 1. Landing mat design barrier.

Appendix B describes a detailed engineering inspection of the 14 miles of fencing at the San Diego/Tijuana border. This fencing is predominantly of the landing mat design.

Pre-Cast Concrete Panels

Concrete panels 15-ft high, 12-ft long, 4-in. wide are held in place by 4-in. carbon steel I-beams mounted in 16-in. concrete piers to a depth of 8 ft. Each panel weighs approximately 10,000 lb and is manufactured offsite at a central processing location. Similar fences have been used as sound and visual barriers along U.S. highways nationwide. Carbon steel I-beams (improved active degradation resistance) measuring 8 in. can be substituted for an approximate $15,000 additional per mile. Terrain and topographic concerns may cause difficulty. For steep hill regions, fence panels would require stepping or terracing to accommodate I-beam design constraints. This consequence necessarily enhances construction difficulty because of increased ground preparation time. Dig-under protection can be added without price increase by simply burying 2 ft of the panel below grade, leaving a 13-ft high barrier above grade.

Bollard Design - Bare

Figure 2 shows 12-in.-diameter concrete bollard fence staggered every 5 in. along the fence line. Poles are 12-ft high, buried to a depth of 2 ft, and anchored in concrete. Certain areas of fence are also equipped with 48-in. steel outriggers and wire mesh mounted atop bollard poles. The concrete bollard fence requires surveying of the installation site and concrete forms for installation. Any damage to the concrete requires forms to hold the concrete in place until cured. Approximately 1,000 ft of bollard fence (bare concrete) is being used as a secondary barrier on a trial basis.

Bollard Design - Steel Cased

The concrete bollard design has been modified to address the concern that bare concrete poles would be destroyed by active degradation at an unacceptable rate. The modification encases the bollard poles in steel sheaths (drainage culvert pipe) to prevent chipping and connects the tops of the poles in series to prevent breakage between adjacent poles from pressure applied by automobile jacks. This arrangement alleviates the need for concrete forms used during construction of the poles. However, forms are still needed for constructing the base for the poles. A proposal is under consideration to construct approximately 4,000 ft of bollard fence (steel reinforced) as a primary barrier on a trial basis.

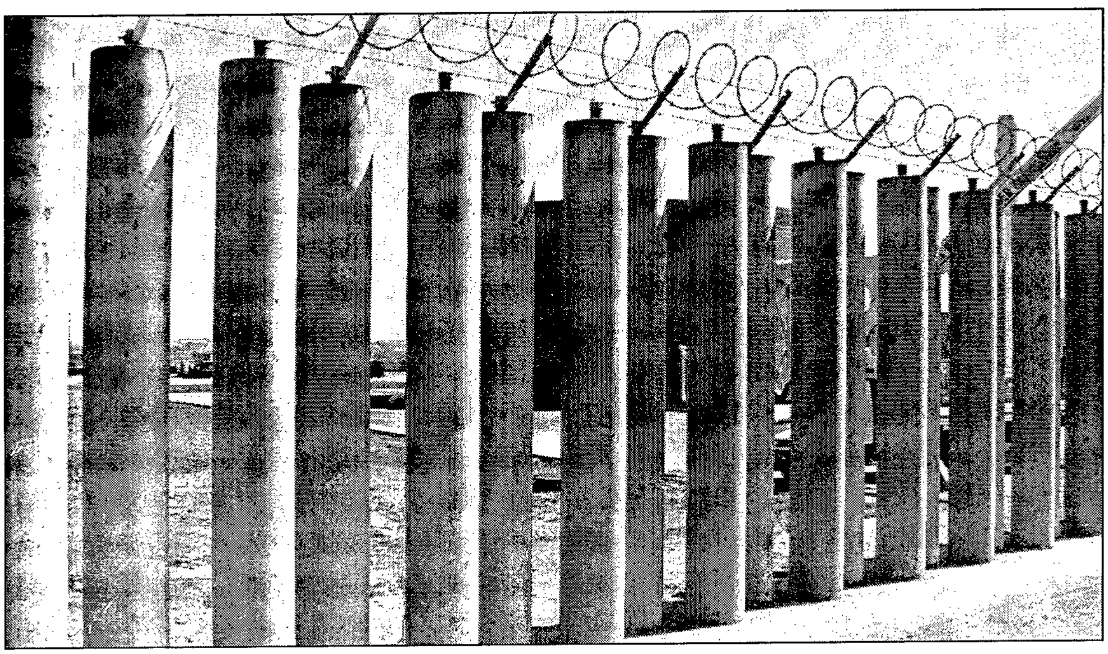

Figure 2. Bare bollard design barrier.

Secondary Barriers

Bollard Designs Considered for Secondary Barrier Service

Both of the bollard designs (i.e., bare concrete and steel cased) being considered for service as a secondary barrier are identical to those being considered for service as a primary barrier. For a full description see the **Primary Barriers** section earlier in this chapter.

Sandia Fence

This angled two-piece fence (shown in Figure 3) is intended to prevent climbing by using gravity and the weight of the trespasser. Posts on 10-ft centers support the fencing. All clamps and bolts are corrosion-resistant galvanized steel.

First DeFence®

This patented fence design (shown in Figure 4) is used in many detention centers. The curved fence design and small gauge mesh of the fence hamper climbing. Posts are centered every 10 ft for support.

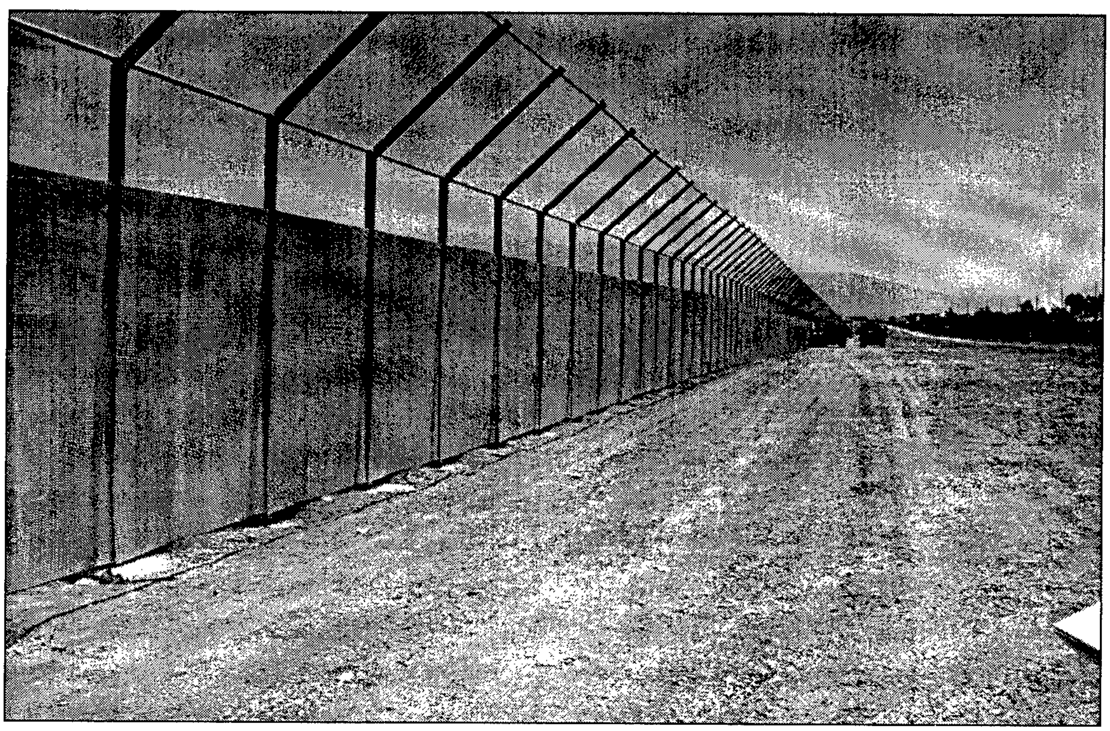

Figure 3. Sandia Fence design barrier.

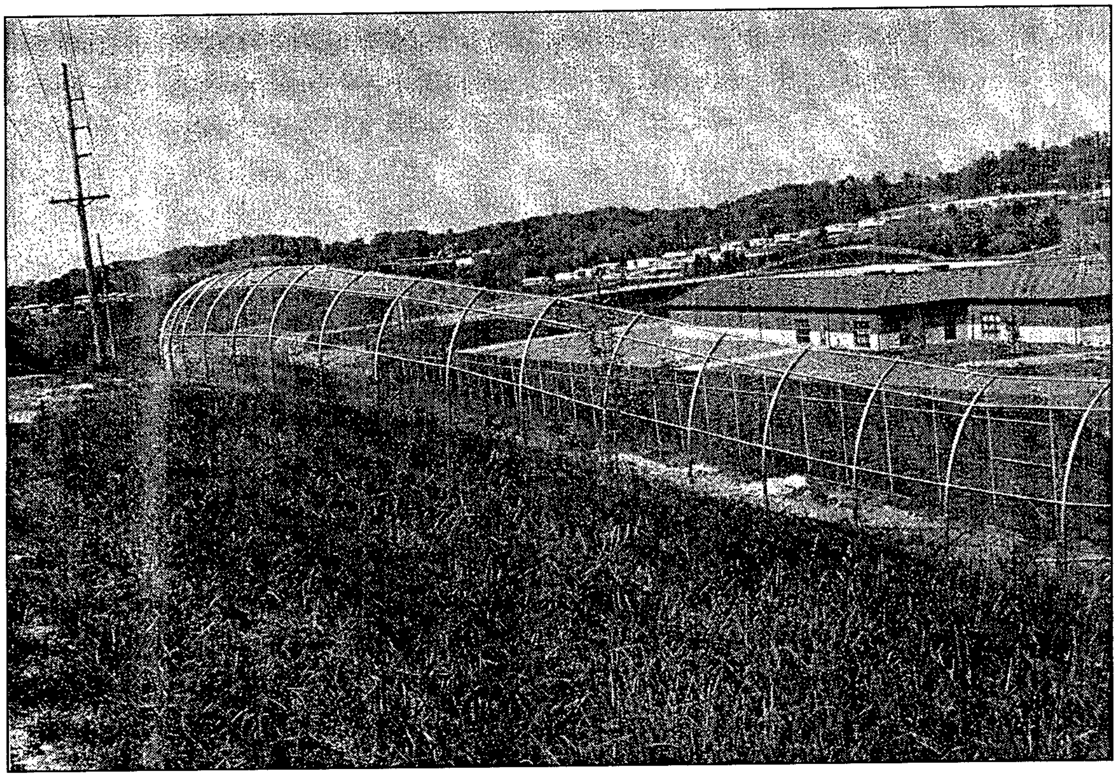

Figure 4. First DeFence® design barrier.

Tertiary Barriers

Chain Link Fence (10-ft high)

This standard steel cyclone fence is made of 9 gauge wire mesh.

Chain Link Fence (6-ft high)

This standard steel cyclone fence is also made of 9 gauge wire mesh.

4 Life-Cycle Cost Analysis, Assumptions, and Results

Global Assumptions and Parameters

Throughout this study it is assumed that, for any new construction, the first 2 years are required for installation and that no maintenance costs are incurred for the first 3 years, inclusive of the installation period. Each life-cycle cost analysis was performed with the software package ECONPACK. The parameters used* are shown in Table 1. Energy costs, including energy escalation factors, were considered incidental and were not included. Each evaluation is based on both the initial construction costs and the ongoing annual operating costs, including the effects of degradation, over a 25-yr analysis period, and all discounted back to a present value. In addition, some engineering judgments were made as to which designs are appropriate for service as a primary, secondary, or tertiary barrier.

Table 1. ECONPACK parameter descriptions and values used for life-cycle cost analyses.

Input Parameter	Value
Global Discounting Convention	Middle-of-year
Period of Analysis	25 years
Discount Rate	6.585%
Analysis Type	Secondary
Cost Input	Dollars
Report Output Type	Current
Project Type	MILCON
Inflation Index	3.4% (flat rate over analysis period)

* As provided by the Corps of Engineers, Fort Worth District.

Both best- and worst-case scenarios were considered for all economic analyses. For the best case scenarios, a number of design-specific and optimistic assumptions were used along with the following global optimistic assumptions:

- maintenance supplies can be easily transported to the fence with only negligible additional cost
- Border Patrol activity is sufficient to prevent any significant attack, or active degradation, on the secondary or tertiary fences
- all needed M&R work is identified immediately and performed rapidly and completely.

Conversely, for the worst case scenarios, a number of design-specific and pessimistic assumptions were used along with the following global pessimistic assumptions:

- an additional 10 percent construction cost and ongoing additional 5 percent maintenance cost are attributable to sloped and rough terrain
- Border Patrol activity is insufficient to prevent active degradation of the secondary barrier, which is comparable to that suffered by the primary barrier
- fence repair is only performed in "break down" situations where individual or vehicle traffic is possible, with all other maintenance being indefinitely postponed.

Hourly Rate Calculation

The hourly rate of $22.60 is a fully burdened average of two potential hourly rates; a low-end rate of $8.00 per hour, and an upper rate of $12.00 per hour. The calculation is as follows:

$$(\$8.00/hr)(2.2) = \$17.60$$
$$(\$12.00/hr)(2.3) = \$27.60$$

$$Average = \frac{[\$17.60 + \$27.60]}{2} = \$22.60$$

Primary Barrier Assumptions

Landing Mat — Optimistic Assumptions

For the existing landing mat, there are no construction costs (materials used are surplus). For this analysis, however, a construction cost of $341,584/mile is assumed for comparative purposes. The total cost of the fence for 14 miles is $4,782,176. The cost is spread over the first 2 years; $2.5 million being accounted for in the first year and $2.3 million in the second. The maintenance costs for 14 miles of fence are assumed to consist of repairing 100 actively degraded sites per year. These acts of degradation might consist of, for example, eight breaches sufficient for human entry per month combined with one vehicle drive-through every 3 months. Material costs are assumed to cover the replacement of 50 panels and each repair is assumed to require 8 man-hours. Panels cost $68 each. At a labor cost of $22.60/man-hour, the total maintenance costs per year come to $21,480.

Landing Mat — Pessimistic Assumptions

Construction costs are assumed to be $379,538/mile (10 percent margin increase because of terrain difficulties) for a total of $5,313,532 for 14 miles. This cost is spread over the first 2 years with $3 million being accounted for in the first year and $2.3 million in the second. The maintenance costs for 14 miles of fence are assumed to consist of repairing 1,000 actively degraded sites per year. These acts of degradation might consist of 80 breaches sufficient for human entry per month combined with 40 drive-throughs annually. Material costs are assumed to cover the replacement of 500 panels and each repair is assumed to require 8 man-hours. Panels cost $76 each ($68 plus a 12 percent increase to account for terrain difficulties). At a labor cost of $22.60/man-hour, the total maintenance costs per year comes to $218,800.

Pre-Cast Concrete Panels — Optimistic Assumptions

Construction costs are assumed to be $630,000/mile for a total of $8,890,000 for 14 miles. This cost is spread over the first 2 years with $5 million being accounted for in the first year and $3.89 million the second. It is assumed that no maintenance costs are incurred during the first 2 years. In the third year, the only maintenance cost consists of stockpiling approximately 5 percent (300 panels) of the total number of panels (6,160). At a per panel cost of $450, the total comes to $135,000. For years 4 and 5, maintenance consists of replacing 100 panels per year. A cost of $22.60/man-hour and 8 man-hours/panel is assumed for a total cost of $18,080. Thereafter, further stockpiling of 300 panels (material cost of $135,000) every third year (starting in year 7) and a yearly replacement of 100 panels (labor cost of $18,080) is assumed.

Pre-Cast Concrete Panels— Pessimistic Assumptions

Construction costs are assumed to be $705,555/mile for a total of $9,877,770 for 14 miles. This cost is spread over the first 2 years with $5.6 million being accounted for the first year and $4.3 million the second. It is assumed that no maintenance cost are incurred the first 2 years. In the third year, the only maintenance cost consists of stockpiling approximately 10 percent (600 panels) of the total number of panels (6,160). At a per panel cost of $474 the total comes to $284,400. For years 4, 5, and 6, maintenance consists of replacing 200 panels per year. A cost of $22.60/man-hour and 8 man-hours/panel is assumed for a total cost of $36,160. Thereafter further stockpiling of 600 panels (material cost of $284,400) every third year (starting in year 7) and a yearly replacement of 200 panels (labor cost of $36,160) is assumed.

Bollard Design (Bare) - Optimistic Assumptions

Construction costs are assumed to be $1,667,000/mile for a total of $23,338,000 for 14 miles. This cost is spread over the first 2 years, with $13.3 million being accounted for in the first year and $10 million in the second. It is assumed that no maintenance costs are incurred for the first 3 years. For year 4 and thereafter, it is assumed that maintenance will consist of replacing 28 poles (2 poles/mile) per year. Assuming a per pole replacement cost of $500 for both labor and materials, the yearly maintenance costs come to $14,000.

Bollard Design (Bare) - Pessimistic Assumptions

Construction costs are assumed to be $1,852,225/mile for a total of $25,931,150 for 14 miles. This cost is spread over the first 2 years, with $15 million being accounted for in the first year and $10.9 million in the second. It is assumed that no maintenance costs are incurred for the first 3 years. For year 4 and thereafter, it is assumed that maintenance will consist of replacing 420 poles (30 poles/mile) per year. Assuming a per pole replacement cost of $526 for both labor and materials, the yearly maintenance costs come to $220,920.

Bollard Design (Steel Cased) - Optimistic Assumptions

Construction costs are assumed to be $2,083,750/mile for a total of $29,172,500 for 14 miles. This cost is spread over the first 2 years with $15.5 million being accounted for in the first year and $13.7 million the second. It is assumed that no maintenance costs are incurred for the first 3 years. For year 4 and thereafter, it is assumed that maintenance will consist of replacing 28 poles (2 poles/mile) per year. Assuming a per pole replacement cost of $625 for both labor and materials, the yearly maintenance costs come to $17,500.

Bollard Design (Steel Cased) - Pessimistic Assumptions

Construction costs are assumed to be $2,315,280/mile for a total of $32,413,920 for 14 miles. This cost is spread over the first 2 years with $17.2 million being accounted for in the first year and $15.2 million in the second. It is assumed that no maintenance costs are incurred for the first 3 years. For year 4 and thereafter, it is assumed that maintenance will consist of replacing 420 poles (30 poles/mile) per year. Assuming a per pole replacement cost of $658 for both labor and materials, the yearly maintenance costs come to $276,360.

Secondary Barrier Assumptions

Bollard Design

The optmistic and pessimistic assumptions for the bollard design (both bare and steel cased) are identical to those used for the primary barrier.

Sandia Fence - Optimistic Assumptions

Construction costs for the first year are assumed to total $9,683,520 for 14 miles. Damage to fencing by active degradation is assumed to be negligible. Beginning in year 2, a minimal amount of maintenance of 10 man-hours per week for upkeep is assumed to be required. At a rate of $22.60/man-hour, the yearly maintenance costs come to $11,752.

Sandia Fence - Pessimistic Assumptions

Construction costs for the first year are assumed to total $10,759,467 for 14 miles. Beginning in year 2, damage to fencing is assumed to be severe and ongoing. For years 2, 3, and 4, maintenance of 80 man-hours per week is assumed. At a rate of $22.60 per man-hour, the yearly maintenance costs come to $94,016. In the fifth year (and every fourth year thereafter), a complete replacement of the fence is required.

First DeFence® - Optimistic Assumptions

Construction costs for the first year are assumed to total $11,679,360 for 14 miles. Damage to fencing by active degradation is assumed to be negligible. Beginning in year 2, minimal maintenance of 10 man-hours/week for upkeep is assumed to be required. At a rate of $22.60/man-hour, the yearly maintenance costs come to $11,752.

First DeFence® - Pessimistic Assumptions

Construction costs for the first year are assumed to total of $12,977,067 for 14 miles. Beginning in year 2, damage to fencing is assumed to be severe and ongoing. For years 2, 3, and 4, maintenance of 80 man-hours/week is assumed. At a rate of $22.60/man-hour, the yearly maintenance costs come to $94,016. In the fifth year (and every fourth year thereafter), a complete replacement of the fence is required.

Tertiary Barrier Assumptions

Chain Link Fence (10-ft high) - Optimistic Assumptions

Construction costs total $770,000. Damage to fencing by active degradation is negligible. To offset damage caused by wind and weather, minor maintenance will be required on a periodic basis. Each year, maintenance of 5 man-hours/week is assumed. At a rate of $22.60/man-hour, the yearly maintenance costs come to $5,876.

Chain Link Fence (10-ft high) - Pessimistic Assumptions

Construction costs total $855,555. Beginning in year 2 damage to fencing is assumed to be severe and ongoing. For years 2, 3, and 4, maintenance of 40 man-hours/week is assumed. At a rate of $22.60/man-hour, the yearly maintenance costs come to $47,008. In the fifth year (and every fourth year thereafter), a complete replacement of the fence is required.

Chain Link Fence (6-ft high) - Optimistic Assumptions

Construction costs total $622,500. Damage to fencing by active degradation is negligible. To offset damage caused by wind and weather, minor maintenance will be required on a periodic basis. Each year, maintenance of 5 man-hours/

week is assumed. At a rate of $22.60/man-hour, the yearly maintenance costs come to $5,876.

Chain Link Fence (6-ft high) - Pessimistic Assumptions

Construction costs total $691,667. Beginning in year 2, damage to fencing is assumed to be severe and ongoing. For years 2, 3, and 4, maintenance of 40 man-hours/week is assumed. At a rate of $22.60/man-hour, the yearly maintenance costs come to $47,008. In the fifth year (and every fourth year thereafter), a complete replacement of the fence is required.

Primary Barrier Results

Each primary barrier was investigated as a possible alternative using the ECONPACK software package. Figures 5 through 8* illustrate the net present values (NPVs) of each of the options described below.

The landing mat fence returned a 25-yr cumulative NPV of $4.7 million in the optimistic case. Because of the assumptions used, the NPV remained relatively flat over the range of the study. Conversely, the pessimistic case yielded a 25-yr cumulative NPV of $7.3 million. This value increased quadratically over the range, as depicted in Figure 6.

The pre-cast concrete panel fence design returned a 25-yr cumulative NPV of $9.0 million in the optimistic case. Because of the assumptions used, the NPV remained relatively flat over the range of the study. Conversely, the pessimistic case yielded a 25-yr cumulative NPV of $10.7 million. This value increased linearly over the range, as depicted in Figure 7.

The bare bollard fence design returned a 25-yr cumulative NPV of $22.2 million and the steel bollard produced $27.6 million in the optimistic case. Because of the assumptions used, the NPV remained relatively flat over the range of the study. Conversely, the pessimistic case yielded a 25-yr cumulative NPV of $26.6 million for the bare design and $33.2 million for the steel reinforced design. These values increased linearly over the range, as depicted in Figure 8.

* OPT/PES = optimistic and pessimistic assumptions, respectively; LDMT = landing mat barriers; PCCON = pre-cast concrete panels; BRBOL = bare bollard fencing; STBOL = steel bollard fencing.

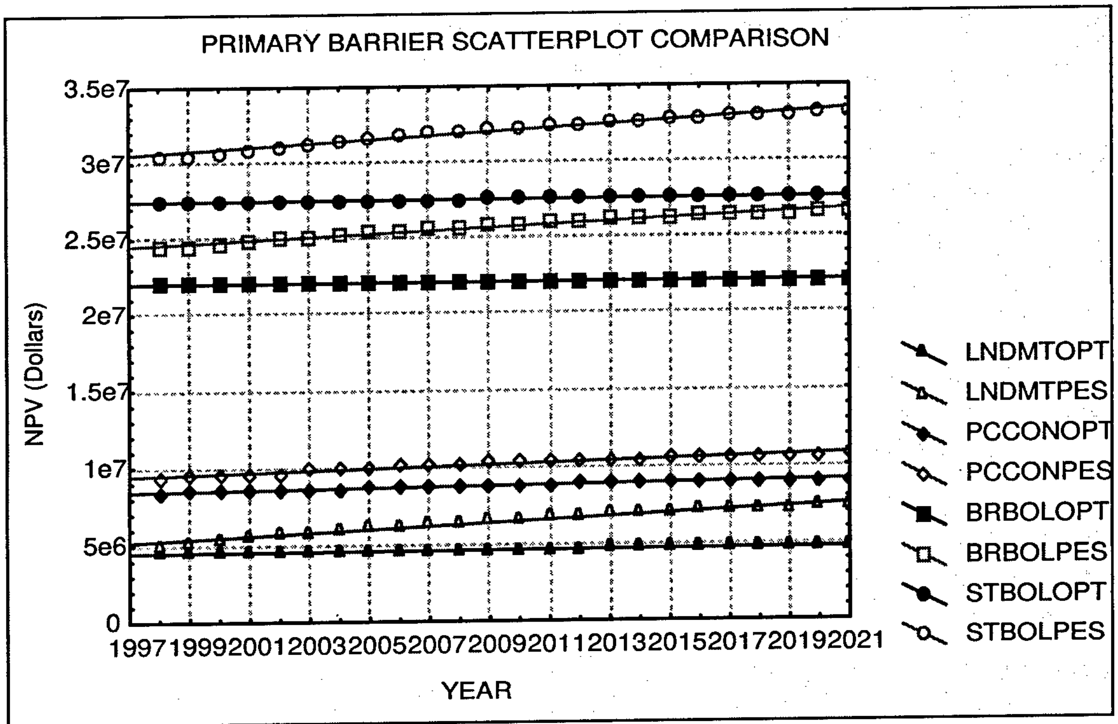

Figure 5. Primary barrier net present value (NPV) comparison.

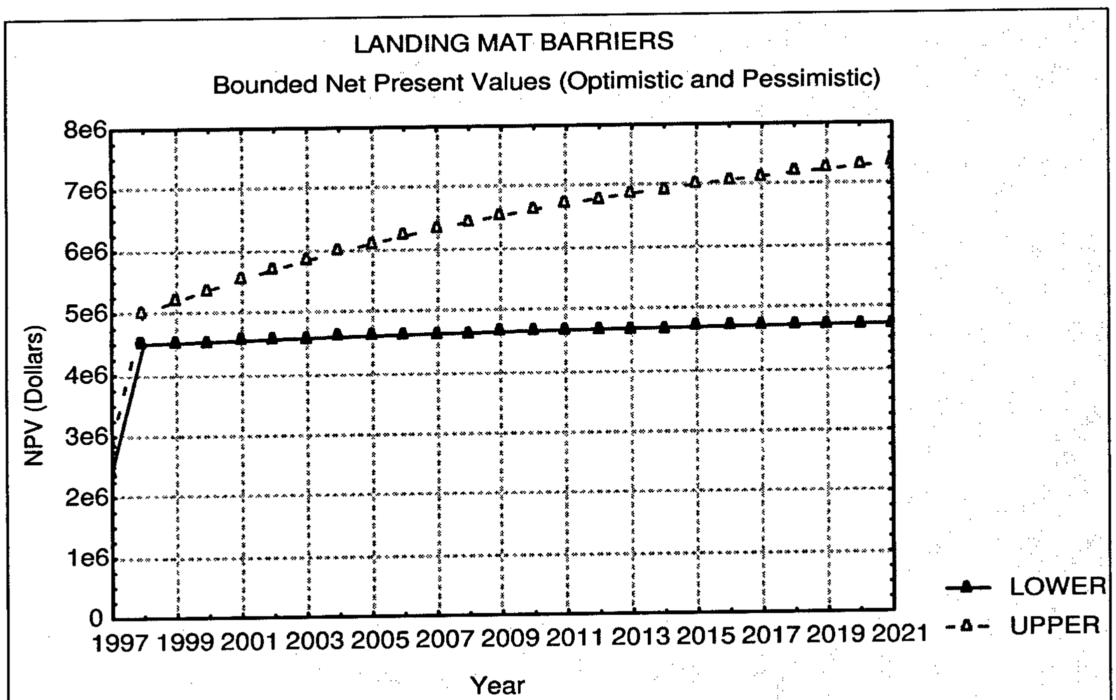

Figure 6. Landing mat barrier NPV comparison.

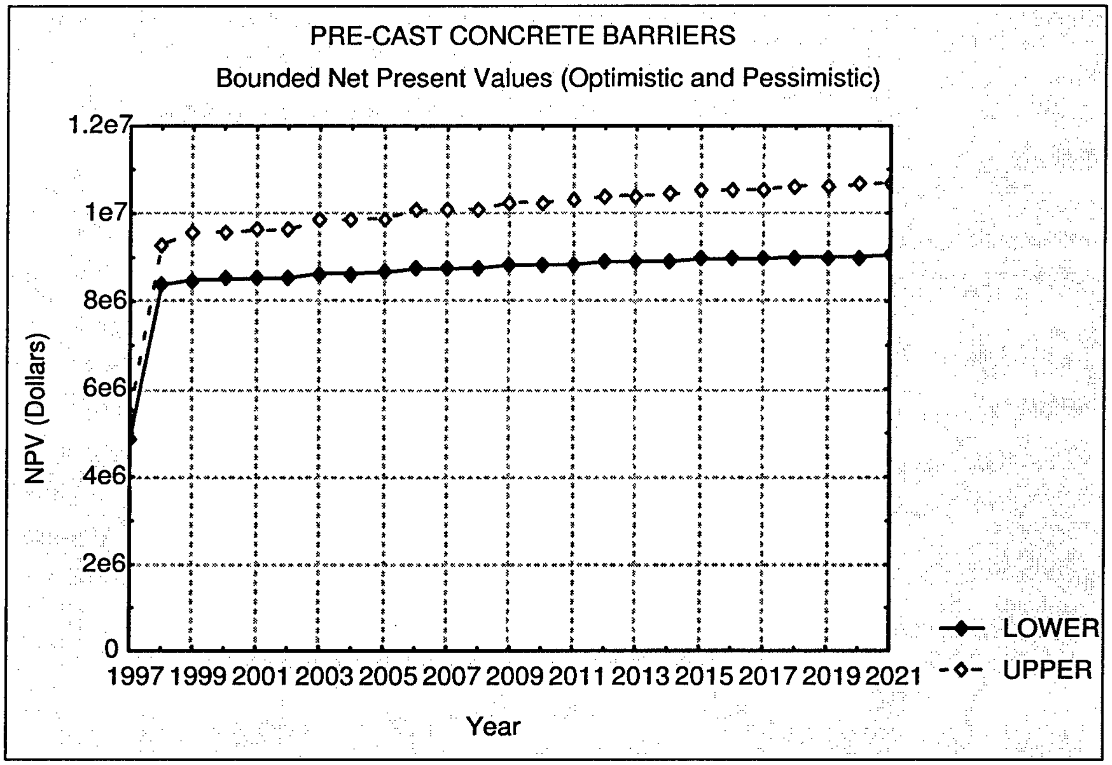

Figure 7. Pre-cast concrete panel barrier NPV comparison.

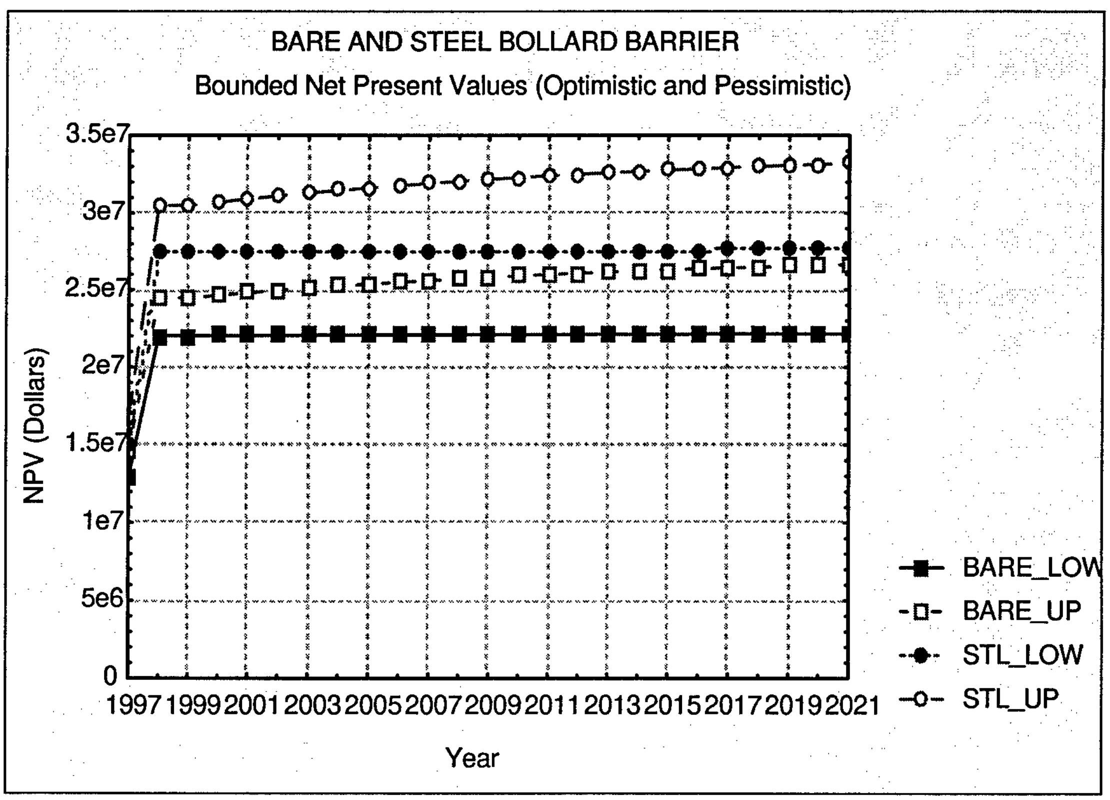

Figure 8. Bollard fence barrier NPV comparison.

Secondary Barrier Results

Each secondary barrier was investigated as a possible alternative using the ECONPACK software package. The bollard fence results are the same as summarized in the previous section. The Sandia fence returned a 25-yr NPV of $9.7 million in the optimistic case. Because of the assumptions used, the NPV remained relatively flat over the range of the study. Conversely, the pessimistic case yielded a 25-yr cumulative NPV of $54.2 million. This value increased stepwise as depicted in Figure 9.

The First DeFence® barrier returned a 25-yr cumulative NPV of $11.7 million in the optimistic case. Because of the assumptions used, the NPV remained relatively flat over the range of the study. Conversely, the pessimistic case yielded a 25-yr cumulative NPV of $65.1 million. This value increased stepwise as depicted in Figure 10.

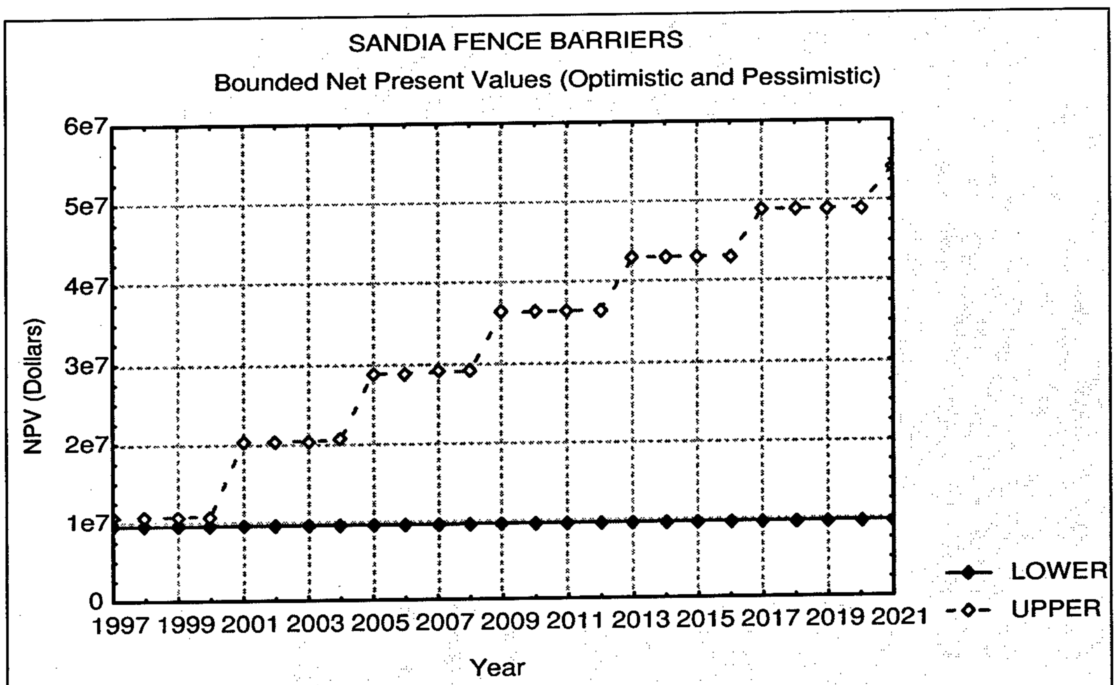

Figure 9. Sandia fence NPV comparison.

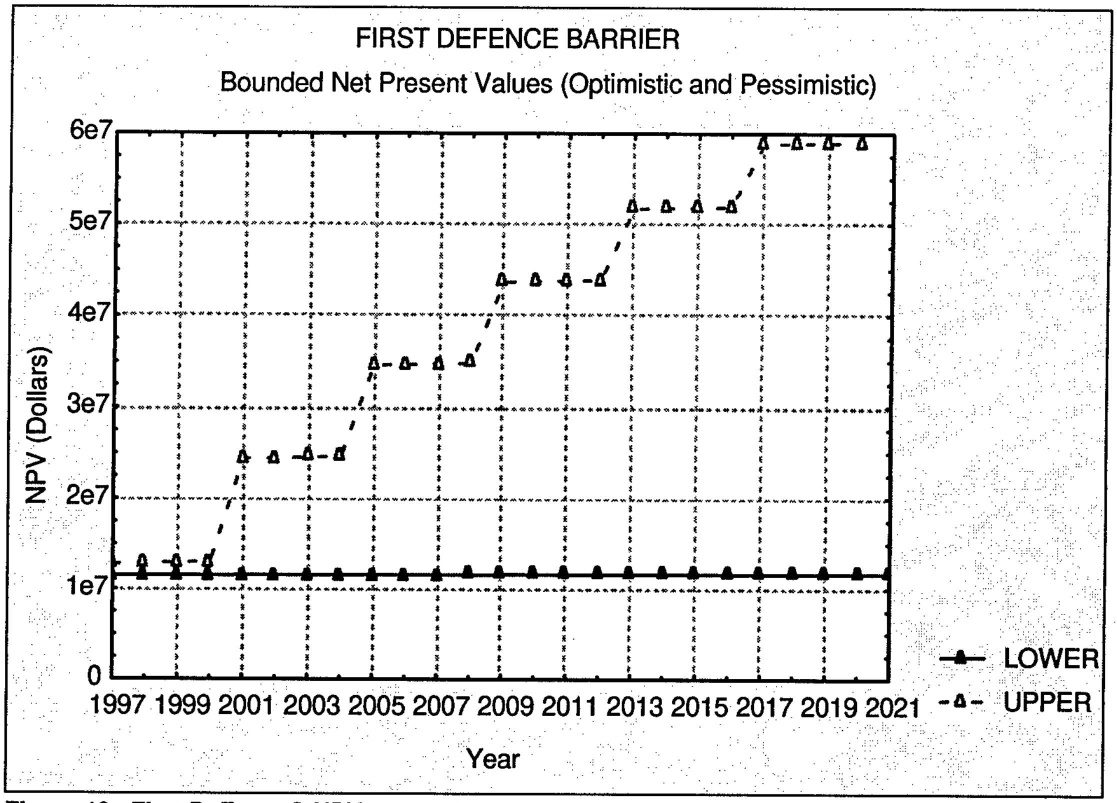

Figure 10. First DeFence® NPV comparison.

Tertiary Barrier Results

Both tertiary barriers were investigated as possible alternatives using the ECONPACK software package. The 6-ft chain link fence returned a 25-yr cumulative NPV of $0.7 million in the optimistic case. Because of the assumptions used, the NPV remained relatively flat over the range of the study. Conversely, the pessimistic case yielded a 25-yr cumulative NPV of $4.0 million. This value increased stepwise as shown in Figure 11.

The 10-ft chain link fence returned a 25-yr cumulative NPV of $0.9 million in the optimistic case. Because of the assumptions used, the NPV remained relatively flat over the range of the study. Conversely, the pessimistic case yielded a 25-yr cumulative NPV of $4.8 million. This value increased stepwise as shown in Figure 11.

Complete NPV reports, as generated by ECONPACK, are included in Appendix C. Table 2 summarizes equipment and maintenance assumptions for the various barrier designs.

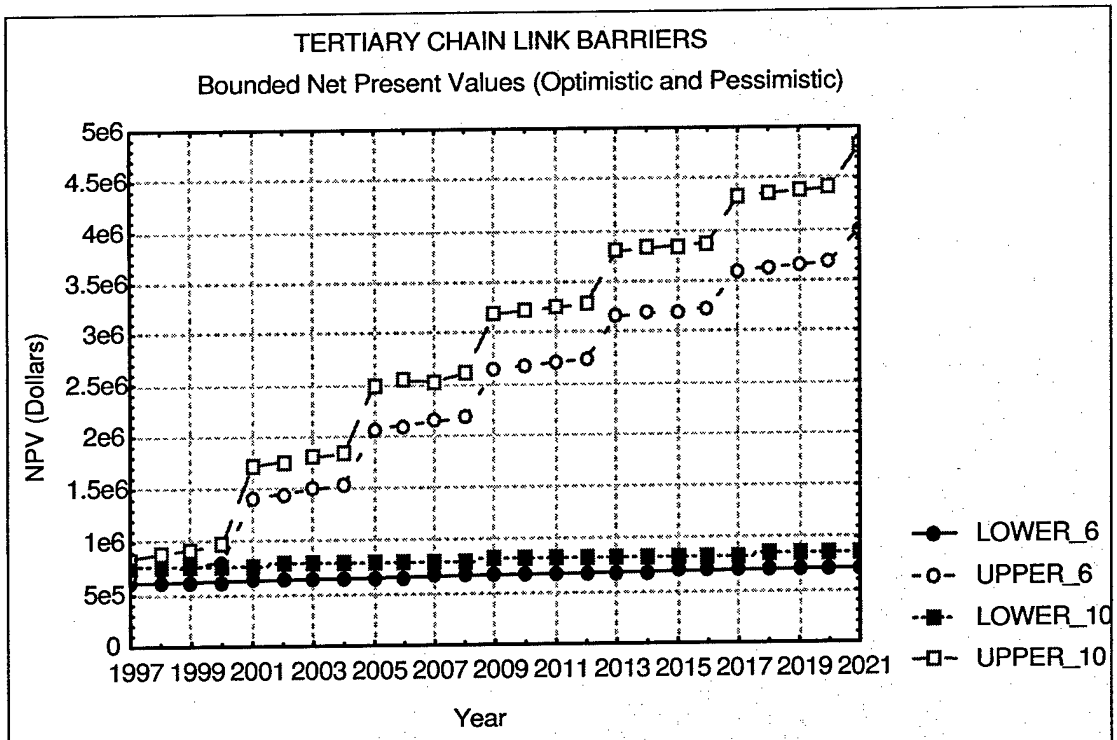

Figure 11. Tertiary barrier NPV comparison.

Table 2. Summary of barrier options with approximate installation costs.

Barriers	Price ($/mile)	Special Equipment	1 Day Repair
Landing Mat	26,400	welding rig	yes
(NO material costs)			
Steel Panel	235,840	welding rig	yes
Bollard Design	1,667,000	forms	no
Cast in Place Concrete	2,030,000	forms/scaffolding	yes
Pre-Cast Concrete	630,000	crane (5 ton min.)	yes
Sandia Design	691,680	yes	
First DeFence® (*)	834,240	no	

* Improvements in the Sandia design have been applied to the First DeFence® design and the adjustment in costs are reflected in the state value. Specifically added to the $124/lin.ft First DeFence® design are:

10-ft x 9-in. galvanized metal to cover joints...........$7.05/lin.ft.
deeper concrete footing (4-ft deep and 4-in. wide) $20/lin.ft.
bottom plate (10 gauge) 6.25-in. x 9-ft ....$6.95/lin.ft.
misc. additional improvements.............................$1.70/lin.ft.

5 Conclusions and Recommendations

Conclusions

Purely on a life-cycle cost basis, the most effective choices are: landing mat (primary), Sandia fence (secondary), and 6-ft chain link (tertiary). However, it is clear that operationally the landing mat primary barrier is inadequate.

Recommendations

Based on the experience gained in the course of this study, it is recommended that:

1. Further systematic effort be put into determining the operational requirements, designing, and optimizing an operational and cost-effective barrier.

2. Sections of these design options be built and tried in practice before widespread implementation in order to obtain operational experience and ongoing maintenance cost data.

3. The option of contracting out fence maintenance be assessed for potential savings and improved fence condition, thus freeing up Border Patrol agents for their primary duties.

References

The Federation for American Immigration Reform, *Ten Steps to Securing America's Borders* (1989).

First DeFence® Security Fence, U.S. Patent Number 4,673,166 (June 16, 1987).

Appendix A: Workshop Attendees

U.S. Immigration & Naturalization Service / U.S. Border Patrol
Barrier System and Road Master Plan, US-Mexico Border, San Diego, CA
Design/Charrette/Workshop 12-14 February 1997

Mr. Milton Blankenship
Joint Task Force Six
Attn: JTFC-J3-EN
Building 11603, Biggs Field
Fort Bliss, TX 79916-0058
915/568-8253 915/568-8092

Ms. Rita Miller
U.S. Department of Justice
INS (INS-ROENG)
24000 Avila Road
Laguna Niguel, CA 92667
714/360-3048 714/360-3013

Dr. Mo Shahin
USACERL
Champaign, IL
217/373-6739 217/373-6740

Mr. F.M. Villafane
U.S. Border Patrol
Liaison Officer, Military Projects
#3 Forrest Gate Road
Campo, CA 91906
619/478-5444

Mr. Andrew R. Jones
U.S. Border Patrol
Chula Vista Station
311 Athey Court
San Ysidro, CA 92173
619/662-7233 619/662-7040

Mr. Eric Verwers
U.S. Army Engineer District - Ft. Worth
Attn: CESWF-EV-R
P.O. Box 17300
Fort Worth, TX 76102-0300
817/978-2370 817/978-7539

Mr. Javier A. Esquivel
U.S. Border Patrol
Chula Vista Station
311 Athey Court
San Ysidro, CA 92173
619/662-7233 619/662-7040

Mr. John J. Strauch
U.S. Border Patrol
Chula Vista Station
311 Athey Court
San Ysidro, CA 92173
619/662-7233 619/662-7040

Dr. Charles Marsh
USACERL
Champaign, IL
217/373-6764 217/373-7222

Mr. Todd L. Birdsong
U.S. Border Patrol
Chula Vista Station
311 Athey Court
San Ysidro, CA 92173
619/662-7233 619/662-7040

Mr. Derek H. Langsford
County of San Diego
Department of Planning and Land Use
5201 Ruffin Road, Suite B
San Diego, CA 92123
619/694-3720 619/694-3373

Mr. Joe Estrada
U.S. Department of Justice
U.S. Border Patrol
425 I Street, NW, Room 4226
Washington, D.C. 20536
202/616-7026 202/514-3478

Ms. Lisa Eskew
U.S. Army Engineer District - Ft. Worth
Attn: CESWF-ED
P.O. Box 17300
Fort Worth, TX 76102-0300
817/978-2288 x1675

Mr. Mead M. Sams
U.S. Army Engineer District - Ft. Worth
Attn: CESWF-EV-M
P.O. Box 17300
Fort Worth, TX 76102-0300
817/978-2025 817/978-7539

CW4 Carl Anderson
California Army National Guard
Team Engineer
3080 Buckman Springs Road
Campo, CA 91906-1210
619/478-2243 619/478-2479

Mr. Joe Funk
U.S. Department of Interior
Bureau of Land Management
P.O. Box 68
Campo, CA 91906
619/557-6144 619/251-4899

Ms. Debra Hood
U.S. Department of Justice
Immigration & Naturalization Service
425 I Street, NW, Room 2102
Washington, D.C. 20536
202/305-4386 202/514-0579

Mr. Hector Montalvo
U.S. Department of Justice
Immigration & Naturalization Service
425 I Street, NW, Room 2060
Washington, D.C., 20536
202/616-7574 202/514-0579

Mr. Dale Bulick
U.S. Army Engineer District-Los Angeles
Attn: CESPL-PM
P.O. Box 532711
Los Angeles, CA 90053-2325
213/452-4010 213/452-4213

Ms. Joy Jyotsna Jaiswal
U.S. Army Engineer District-Los Angeles
Attn: CESPL-PD-RL
P.O. Box 532711
Los Angeles, CA 90053-2325
213/452-3871 213/452-4191

Mr. Alberto Sandoval
Attn: U.S. Border Patrol
24000 Avila Road
Laguna Niguel, CA 92677
714/360-2999 714/360-3135

Mr. Ken Stitt
Assistant Chief Patrol Agent
U.S. Border Patrol
3752 Beyer Boulevard
San Ysidro, CA 92143-9022
619/662-7251 619/662-7029

Mr. Richard Hoffman
USACERL
Champaign, IL
217/373-6739 217/373-6740

Mr. Larry Caver
U.S. Border Patrol
Operation Alliance
P.O. Box 8051
El Paso, TX 79908
915/540-6130 915/540-6198

Mr. Kevin Jackson
U.S. Department of Justice
Immigration & Naturalization Service
425 I Street, NW, Room 2102
Washington, D.C., 20536
202/305-0009 202/514-0579

Mr. Robert Coangelo
U.S. Army Engineer District - Los Angeles
Attn: CESPL-RE
P.O. Box 532711
Los Angeles, CA 90053-2325
213/452-3122 213/452-4186

Mr. Ramon Provencio
Chief, Facilities Maintenance
U.S. Border Patrol
3752 Beyer Boulevard
San Ysidro, CA 92143-9022
619/662-7218 619/662-7219

Mr. Joe Granata
Chief, Facilities Division
U.S. Border Patrol
3752 Beyer Boulevard
San Ysidro, CA 92143-9022
619/662-7218 619/662-7219

Mr. John Bradley
U.S. Fish & Wildlife Service
Carlsbad Field Office
2730 Loker Avenue West
Carlsbad, CA 92008
619/431-9440 619/431-9624

Mr. Dick Guthrie
U.S. Army Engineer District-Los Angeles
Attn: CESPL-RE
P.O. Box 532711
Los Angeles, CA 90053-2325
213/452-3118 213/452-4186

Mr. James Haynes
U.S. Army Engineer District-Los Angeles
Attn: CESPL-RE
P.O. Box 532711
Los Angeles, CA 90053-2325
213/452-3146 213/452-4186

Mr. Mike Trial
U.S. Army Engineer District-Los Angeles
Attn: CESPL-PM
P.O. Box 532711
Los Angeles, CA 90053-2325
213/452-3979 213/452-4213

Mr. Tom Stahl
Assistant U.S. Attorney
880 Front Street, Room 6239
San Diego, CA 92101-8893
619/557-7122

Mr. Greg Pryor
County of San Diego
Director, Planning and Land Use
5201 Ruffin Road
San Diego, CA 92123
619/694-3016 619/694-3373

Mr. John Keever, P.E.
U.S. Army Engineer District-Los Angeles
S. California Office (Const. Operations)
5023 4th Street, Building 2640
March AFB, CA 92518
909/655-2101 909/656-4730

Lt. Col. Ron Hooks
California National Guard
Assistant Inspector General
9800 Goethe Road
Sacramento, CA 95826-9101
916/854-3889 916/854-3641

Cpt. Wade D. Rowley
California Army National Guard
Commander, Team Engineer
3080 Buckman Springs Road
Campo, CA 91906
619/478-5301 619/478-2479

Appendix B: Engineering Inspection

Introduction and Background

The majority of illegal immigration and drug trafficking into the United States occurs near population centers along the border between the United States and Mexico. In 1990 the U.S. Border Patrol (BP) installed approximately 1000 ft of fence south of San Diego, CA, beginning at the ocean. The fence generally consists of steel poles set in concrete approximately 12-ft apart onto which surplus steel panels called landing mats are welded. Over the next 2 years, the BP added sections that extended the fence inland. In 1993 the California National Guard and the Army Reserve began to contribute their efforts. The primary border fence is now 14 miles long. This fence has aided the BP by deterring and redirecting illegal border crossings while essentially halting the incidence of "drive-throughs" (previously on the order of 40,000 per year).

On 24-25 June 1997, CW4 Carl Anderson of the California National Guard guided an inspection of the full 14 miles of fence. Performing the inspection were Dr. Ellen Segan and Brian Temple of the U.S. Army Corps of Engineers Construction Engineering Research Laboratories (USACERL). The engineering condition of the primary barrier fencing systems was evaluated. The primary barrier can logically be subdivided into nine regions. Detailed observations from each region are reported in the following sections.

Overall Observations

Support poles varied in size with the majority of those used being 6-in. nominal diameter Schedule 80 or Schedule 120 well casing piping approximately 14-ft long. Each support is set 2- to 3-ft below grade and embedded in a concrete base. Attached horizontally to the supports are sections of surplus steel panel landing mats previously intended for quickly constructing landing runways. Each mat is 12-ft long, 20-in. wide, and weighs approximately 140 lb. The Military Specifications (Mil-Spec) designation is MIL-M-52738B, Types I, II, and III, as specified by government drawings TA13215E2384, TA1321E2385, and TA1321E2386 (see Figure B.1). Six sections of landing mat are hooked together by connecting pins to produce a fence with a 10-ft nominal height. Welding attachment methods varied with one or both ends of the mat being welded, or one or both ends of the connecting pins being welded. Much of the fence also had concrete reinforcement on the northern side to deter "crash throughs." Additional makeshift belowgrade wire mesh was also common to deter illegal entry under the fence. A common and serious problem found was that the generally sandy soil eroded away from the embedded supports. This problem is worsened by the typically hilly terrain.

A much less prevalant primary barrier design is the bollard fence. Currently only one test section is in place. This design consists of 12-ft tall reinforced concrete pillars that are 12 in. in diameter and have an additional reinforcing steel pole in the middle. The concrete pillars are staggered in two rows with a spacing of 4 to 5 in. between them. The existing bollard fence sections are topped with barbed wire. Future design modifications being considered include adding a steel connecting bar on top, increasing the height from grade to 15 ft, and sheathing each pillar with a permanent 12-in. steel drainage tube during construction.

Detailed Inspection

Section 1 – Ocean fence

The first section of primary barrier is the ocean fence shown in Figure B.1. This section has severe corrosion from saltwater exposure. Figure B.2 shows the first subsection, which is usually in contact with sea water except at low tide. Subsection 1 is constructed of hollow vertical steel poles 6 in. in diameter, inserted 5 to 6 in. apart in the sand. The poles are Schedule 80 or 120 and are welded together at the top with 4x6-in. steel bars and buried 12 to 15 ft in the sand. Some poles are not equipped with endcaps. Therefore, some poles are exposed to salt and sand both internally and externally. The fence is approximately 12-ft tall on the beach. Blistering on the poles is evident along with algae and barnacle deposits. The metal has an orange color on surfaces that regularly contact the sea water during high tide.

The landing mats and square pipes are heavily corroded with flaking on the surfaces as shown in Figure B.2, which also shows welds that are broken from the thermal stresses on the landing mats. No paint remains on the landing mats. Figure B.3 shows the landing mat section going up the embankment to a chain link fence. This subsection is heavily corroded from the salty ocean air. Erosion and digging under the fence are major problems for the loose sandy soil on the steep embankment. Figure B.4 shows an area where the bottoms of the fence have been reinforced with concrete to prevent dig-under breaches. The subsection of the fence in contact with saltwater will need to be replaced in 3 to 5 years because of severe corrosion. The other subsections near to the water will require replacement within several years. Cathodic protection should be used with the replacement fence components where applicable. The replacement fence on the embankment and beach will need to be built on a concrete foundation.

On the top of the embankment is a chain link fence. Figure B.5 shows the fence to be approximately 100-yd long. At the far end of the picture is the ocean section of the primary barrier, and in the foreground is the beginning of the inland landing mat fence. Figure B.5 shows the 2- by 3-in. channel bar used for support poles for the diamond mesh bottom and wire-link top. The fence is 10- to 12-ft tall with poles 6-ft apart, embedded in concrete. Most damage is from holes cut in the wire-link portion of the fence. Repairs are crude patches of fence or, as shown in Figure B.6, rebar secured in the opening by wire and rope. The Tijuana bullring is approximately 50-yd south of this fence.

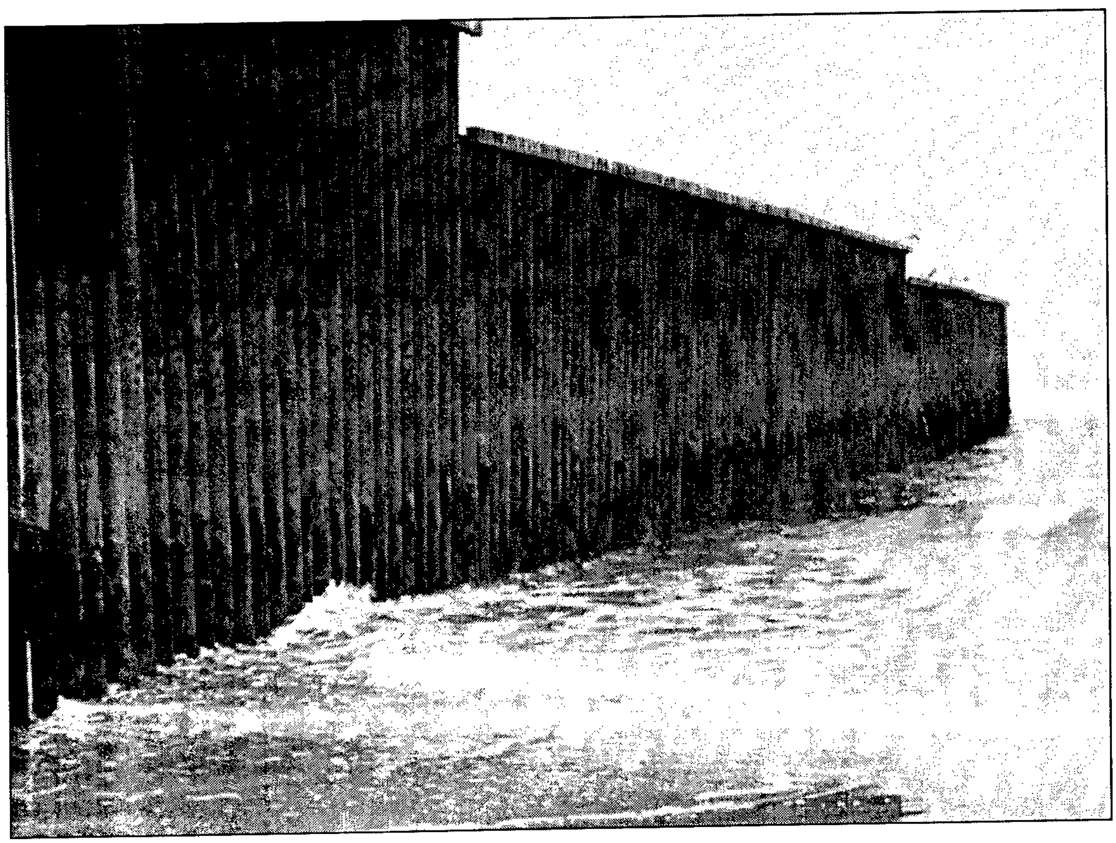

Figure B.1. Sea water corrosion on border fence.

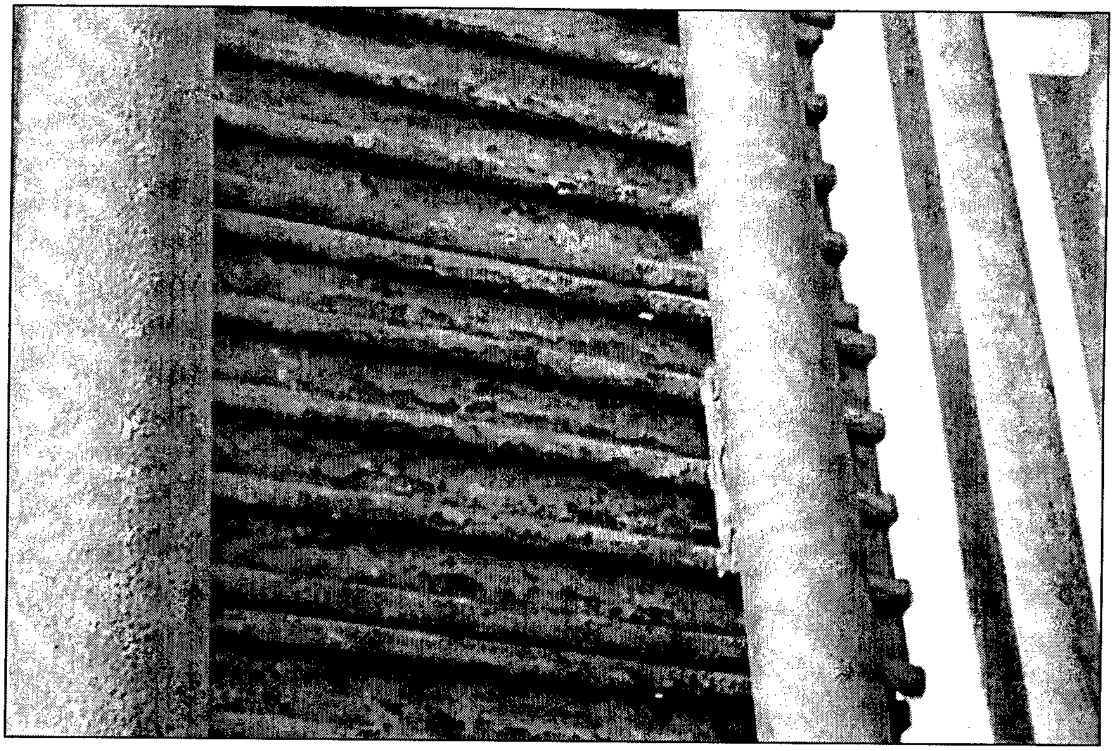

Figure B.2. Welds on landing mats are broken from thermal stresses.

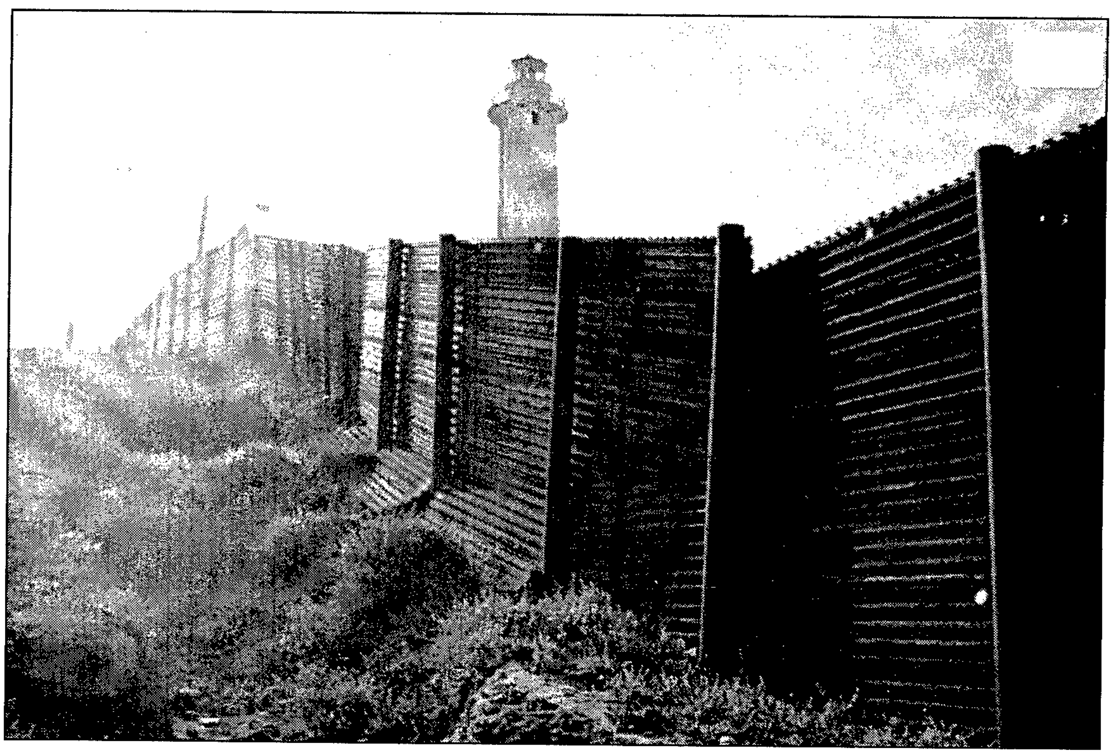

Figure B.3. Landing mat fence extends up the beach to a chain link fence.

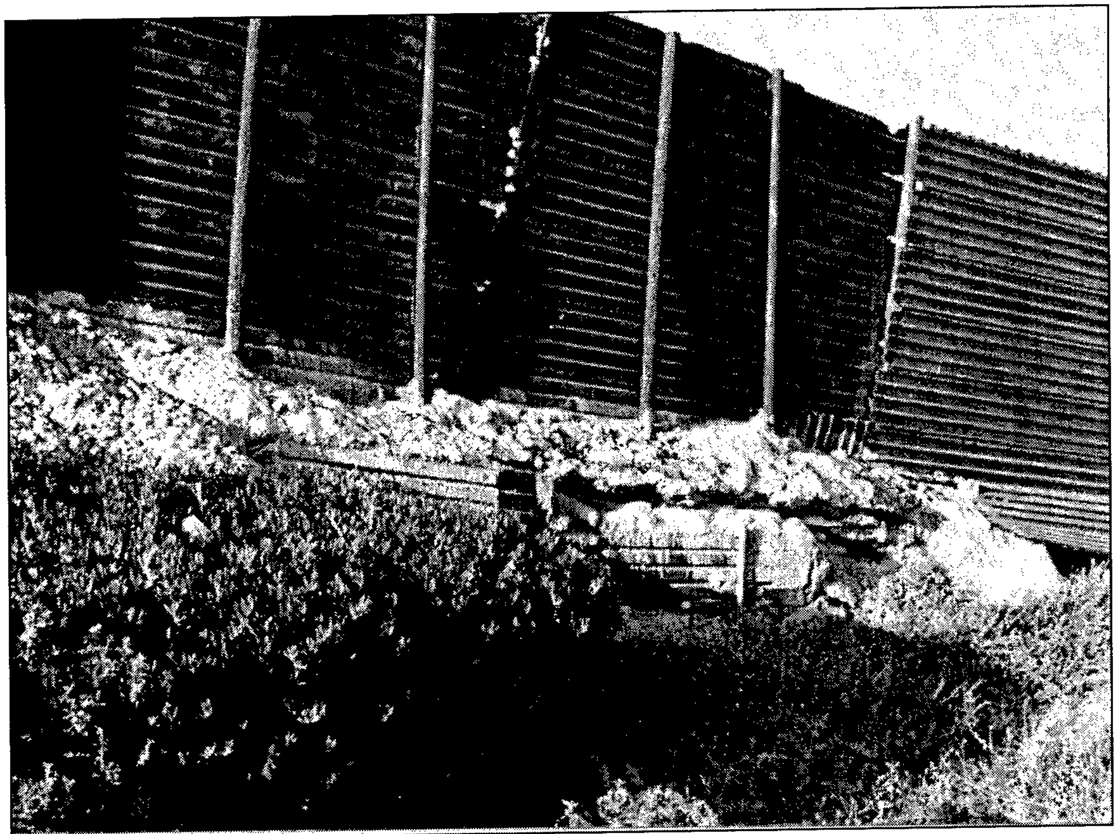

Figure B.4. Concrete poured into holes under the fence as a result of dig-under breaches and erosion of the loose beach sand.

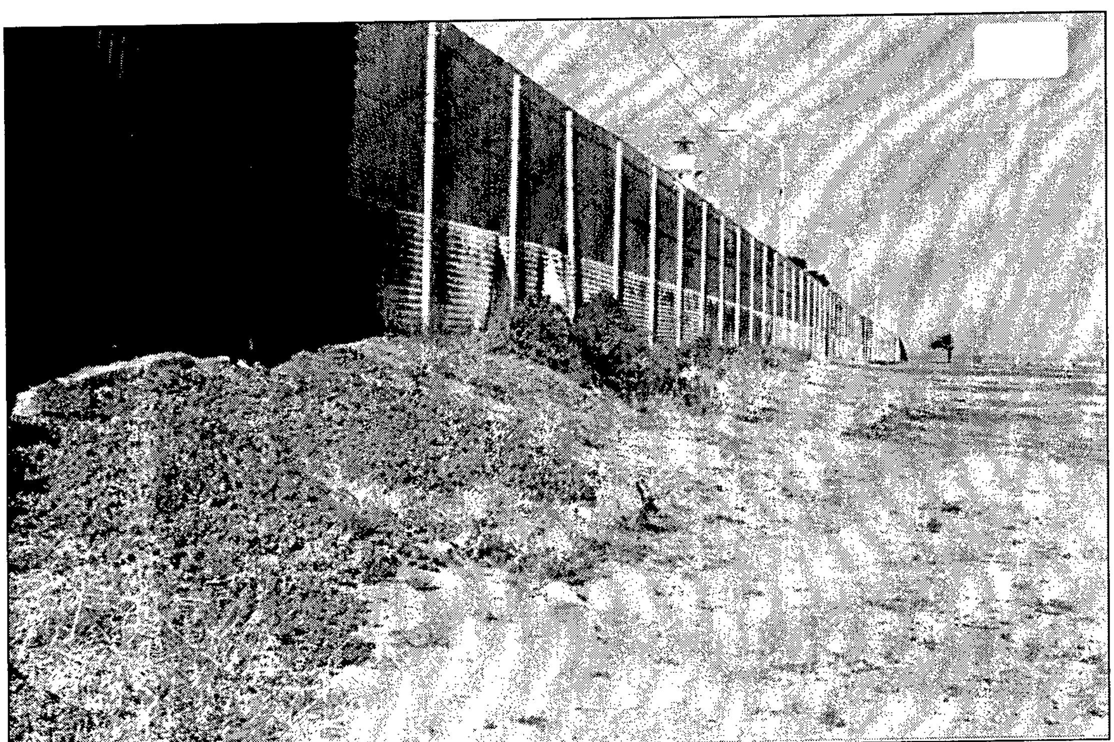

Figure B.5. Chain link fence connects the ocean fence and the first inland section of landing mat fence.

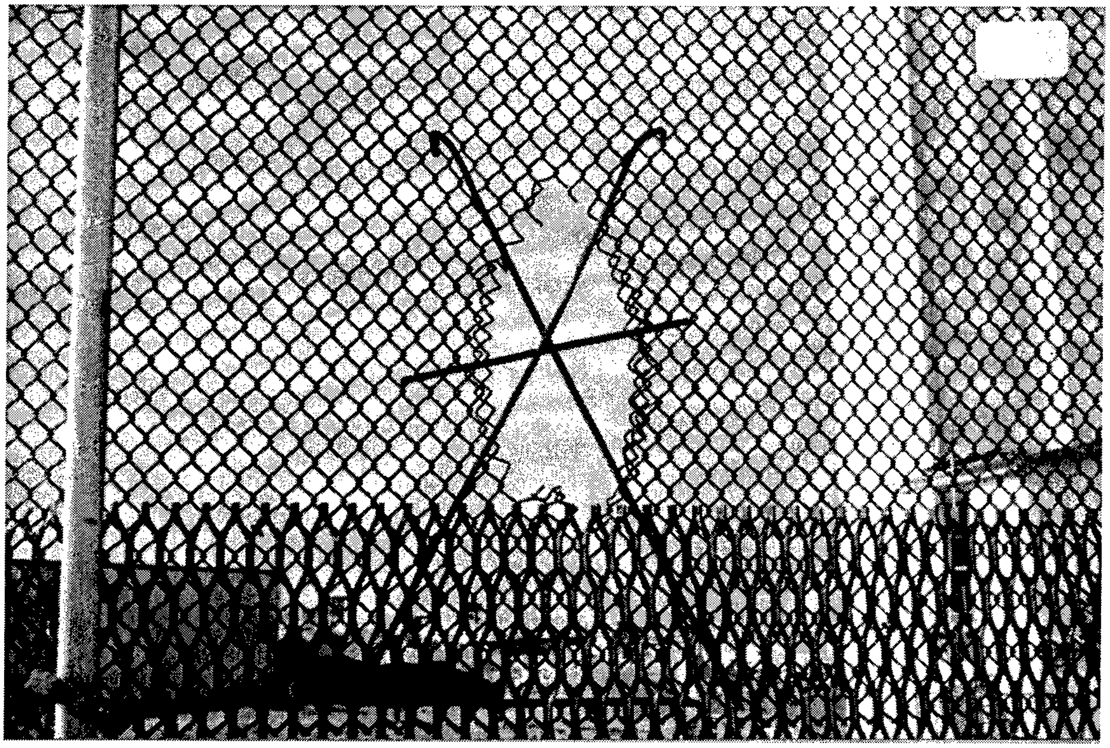

Figure B.6. Ad-hoc repairs to the chain link fence.

Section 2 – 500-ft to 1000-ft inland

Figure B.5 shows the chain link fence that connects to the beginning of the landing mat fence about 500-ft inland. Figure B.7 shows where the fence extends over the hill to a salt marsh that is 1,000 ft inland. Sections are horizontally installed with six panels per section for a height of 10 ft. The original fence used channel bar every 6 ft to support the landing mat sections but was later reinforced with 4.5-in. well casings between the bars as shown in Figure B.8. Close inspection of the landing mat in Figure B.8 shows the mats connected to the support poles by welds and connected to each other by pins welded on both sides. Welding of both sides of the connecting pin restricts thermal expansion of mats and results in the welds to the poles being broken and the fence bending to relieve thermal stress as seen in Figure B.7. One method of relieving the thermal stress is to weld just one side of the connecting pin. The effects of saltwater corrosion lessen significantly just several hundred feet inland. Figure B.8 shows paint on the landing mats with reduced corrosion from the ocean fence sections. The loose sandy soil causes considerable problems from dig-unders and erosion. Figure B.9 was taken 1,000 ft inland in the salt marsh and shows a repair for a dig-under and a cut pole. The poles have been reinforced in concrete so they can hold steady in the loose sandy soil.

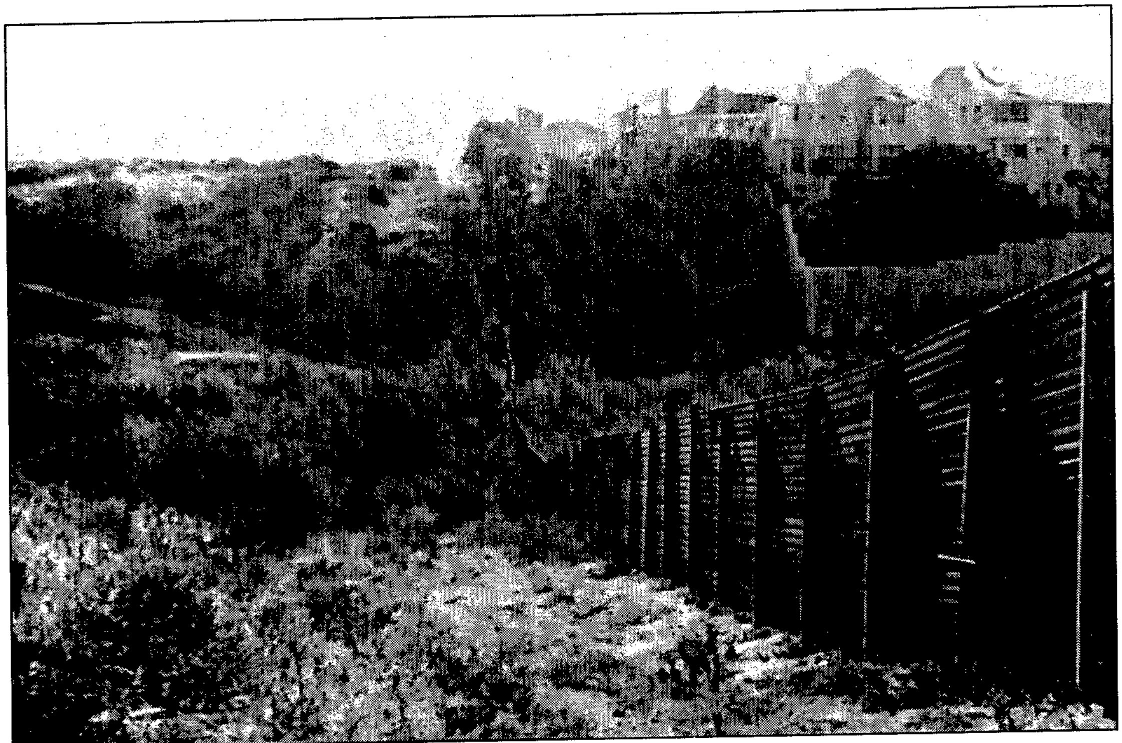

Figure B.7. Fence is bowed from thermal expansion as it extends inland.

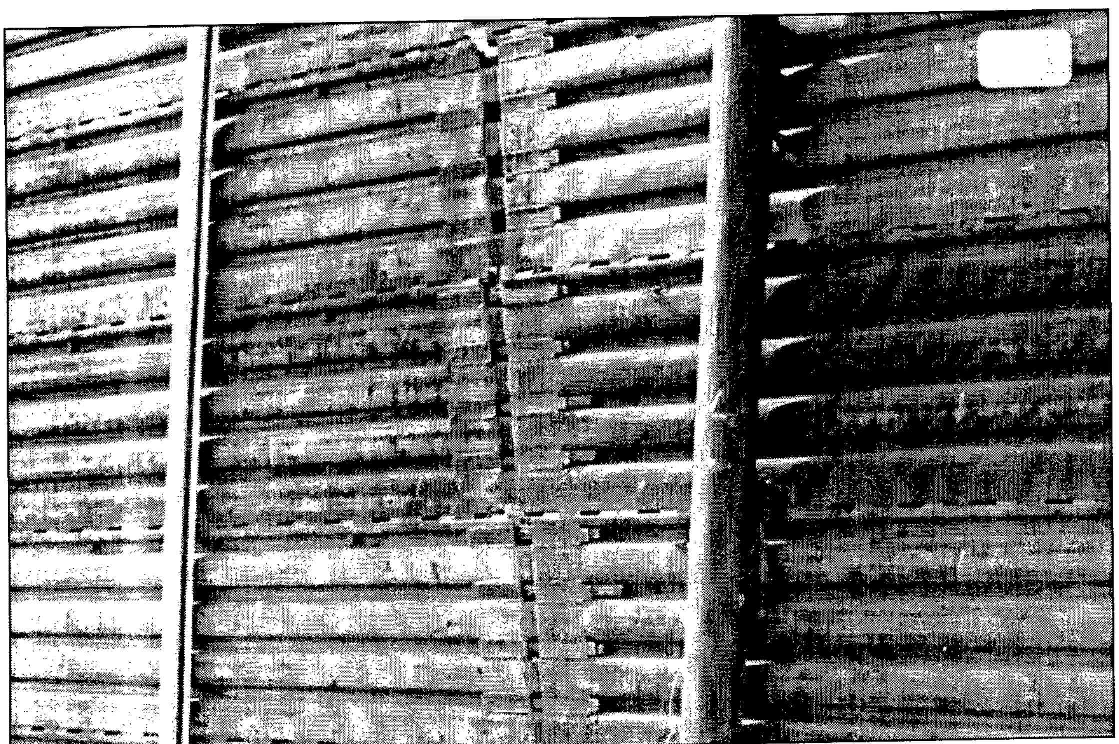

Figure B.8. Mats still have paint only 700 ft inland, and sections are connected by square pins and welded to vertical pipes.

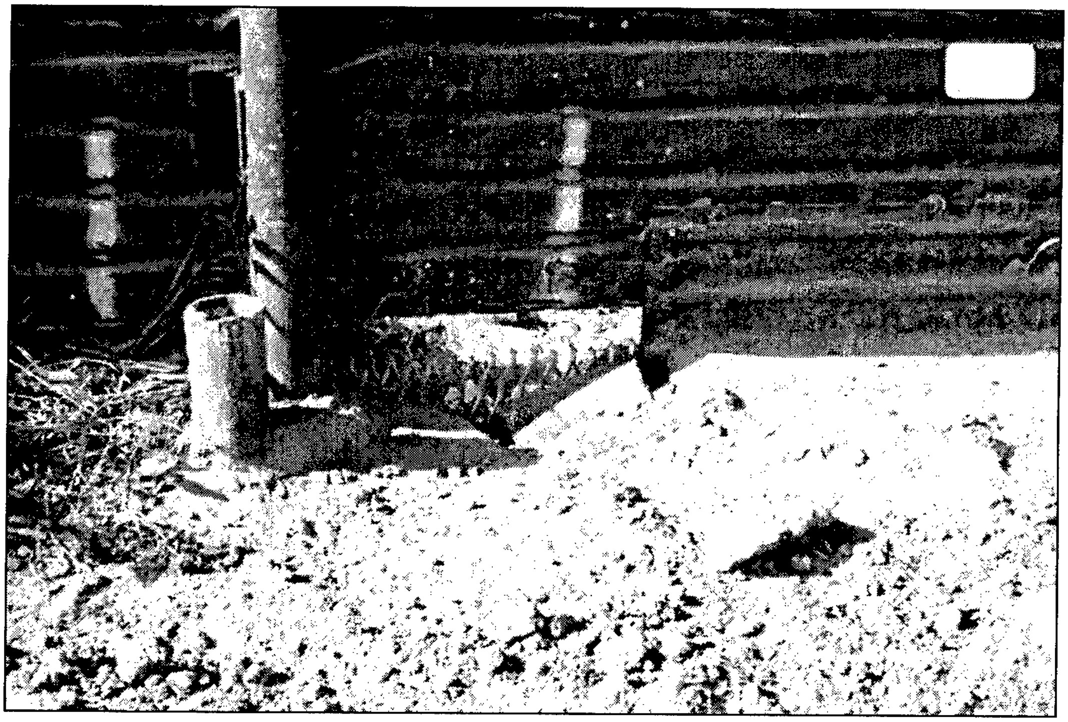

Figure B.9. Dig-under and cut pipe repairs 1,000 ft inland.

Figure B.10 shows drainage tubes under the fence at the bottom of the second hill. These tubes are a high traffic area for crossing. Drainage from rain and sewage flows through the tubes and would clog if gates were installed. The trash could then pile up against the primary barrier. This pile up not only would put an added load on the fence but also could act as a ramp if compacted.

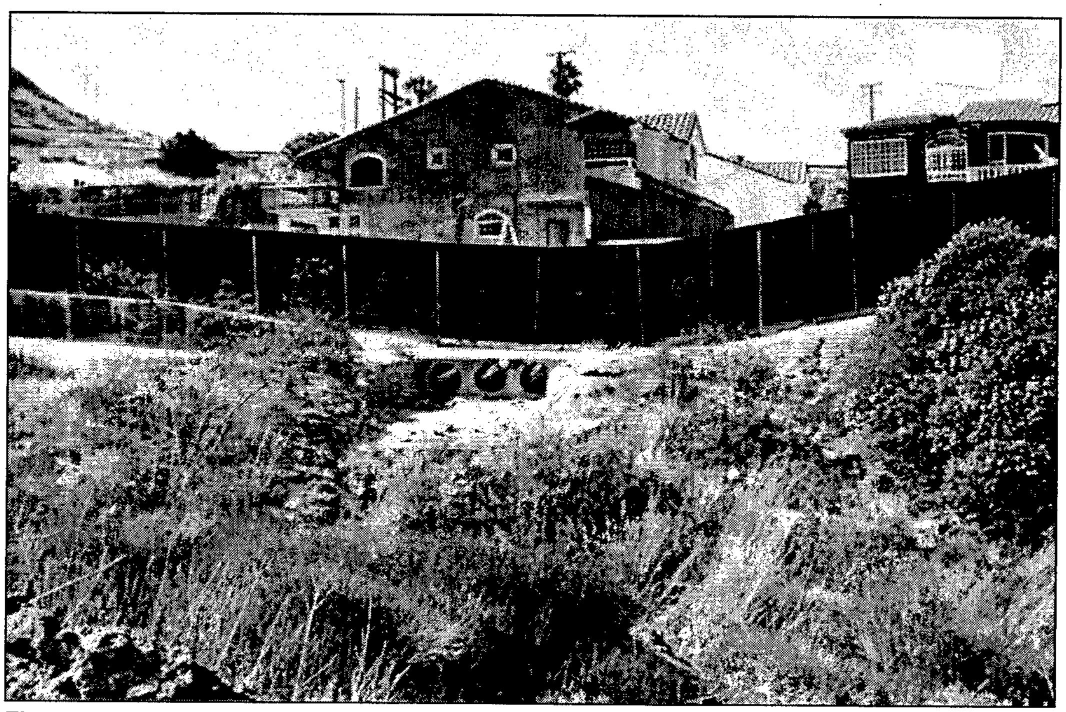

Figure B.10. The high traffic through the drainage tubes under the fence has buffed the metal interior to a shine.

Section 3 – Hilly terrain

Figure B.11 shows the very hilly terrain covered by the barrier fencing. Some areas are left unfenced because of the steep terrain. In this hilly area, the stresses on the welds between sections and the pipes are greater. Figure B.12 shows a mat broken away from the pipe, and Figure B.13 shows how earlier welds between sections have broken. The remedy (also shown in Figure B.13) is to weld only one side of the square pins to allow for thermal stresses. Dig-unders are still common, as are more direct attempts to damage the fence by removing landing mat sections.

Section 4 – Flat region west of hills

Figure B.14 shows the flat region between the San Ysidro border entry and the hills. The United States is to the left of the fence, and a sewage treatment plant is visible in the distance. The secondary bollard fence will be installed on the lower terrain 100-ft north and at a 30-degree angle to the primary fence. The closeness of the Mexican highway and buildings to the fence is apparent. The flat ground and proximity to San Diego's southern suburbs make this a high traffic area for illegal immigration. The ground shown in Figure B.15 will become a retention pond. North of the sewage treatment plant is the maintenance base camp. The fence continues to the Tijuana levee.

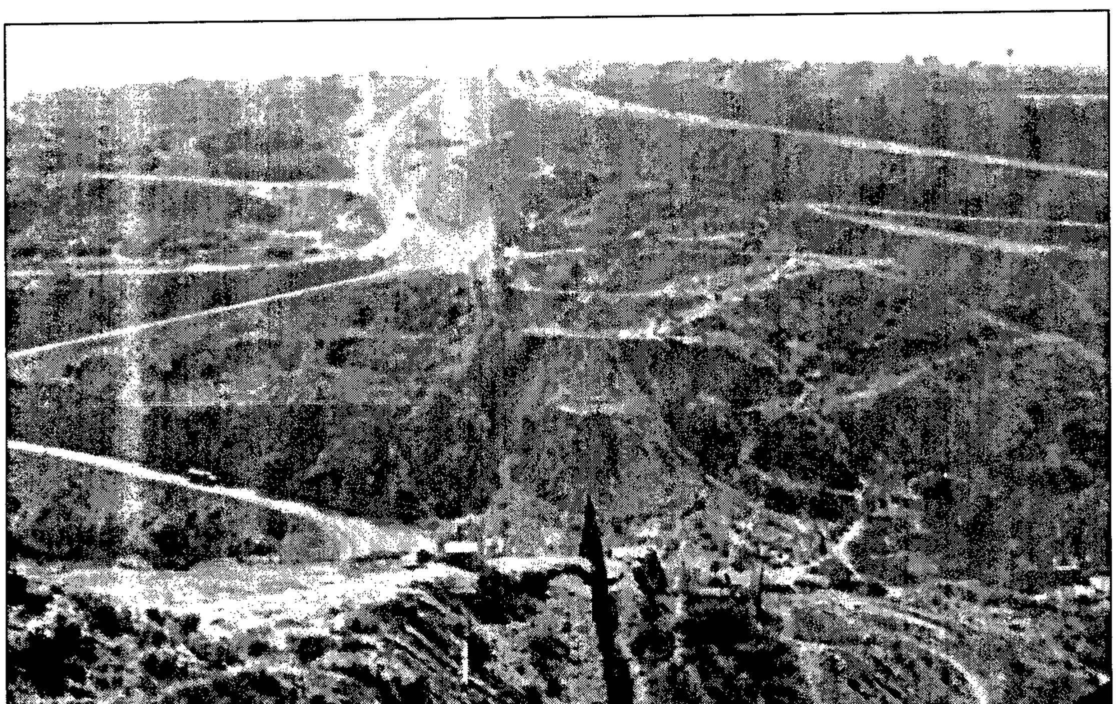

Figure B.11. Part of the hilly terrain covered by the barrier fence.

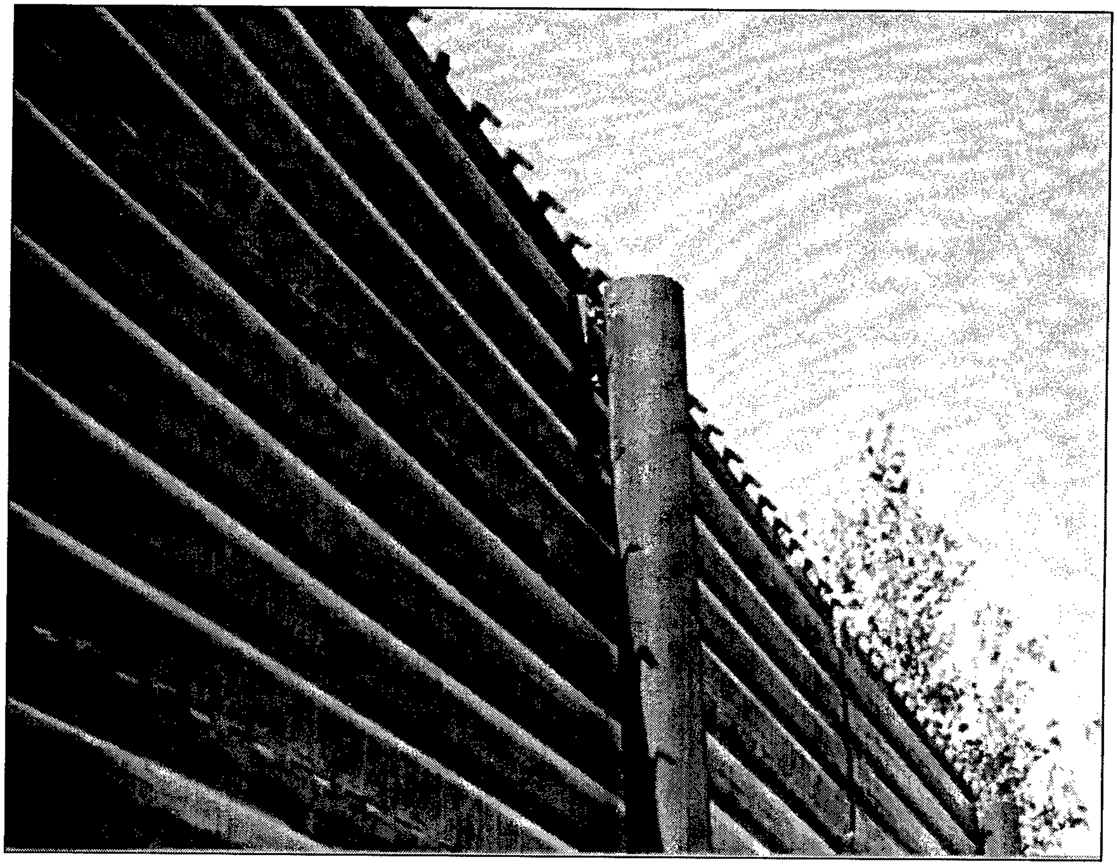

Figure B.12. Welds between the mat and poles are broken from thermal stresses.

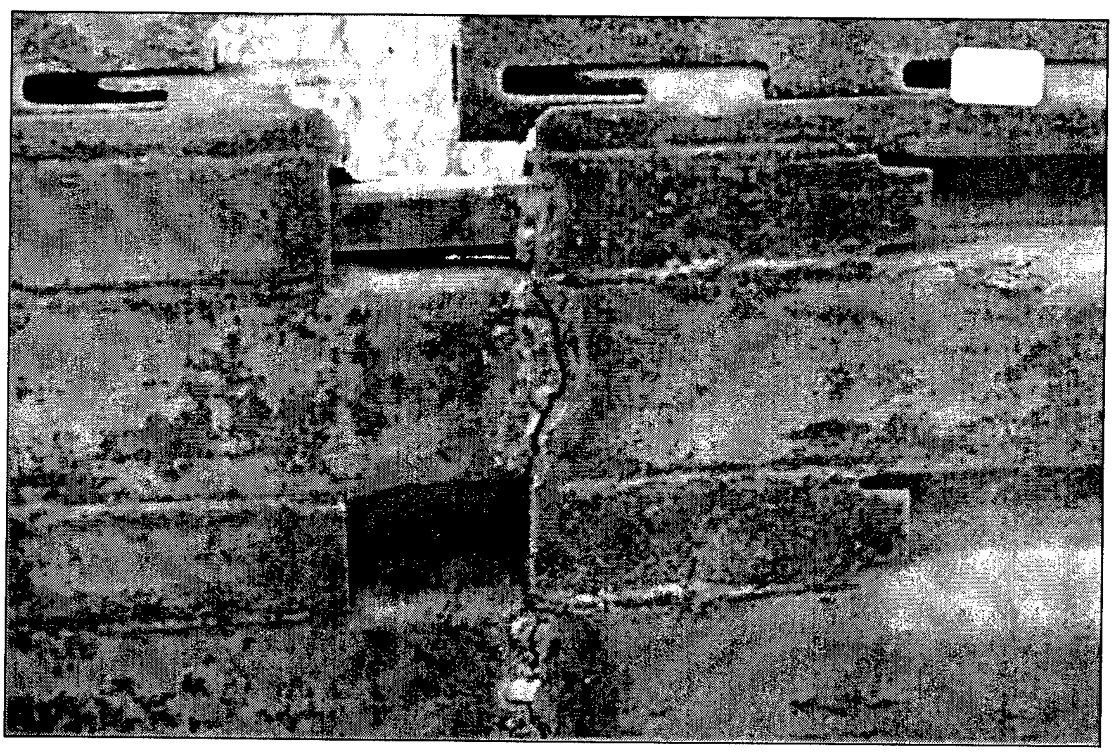

Figure B.13. Broken welds between mats and a repair made by welding one side of the square attachment pin.

Figure B.14. View of the flat ground west of the San Ysidro border entry point.

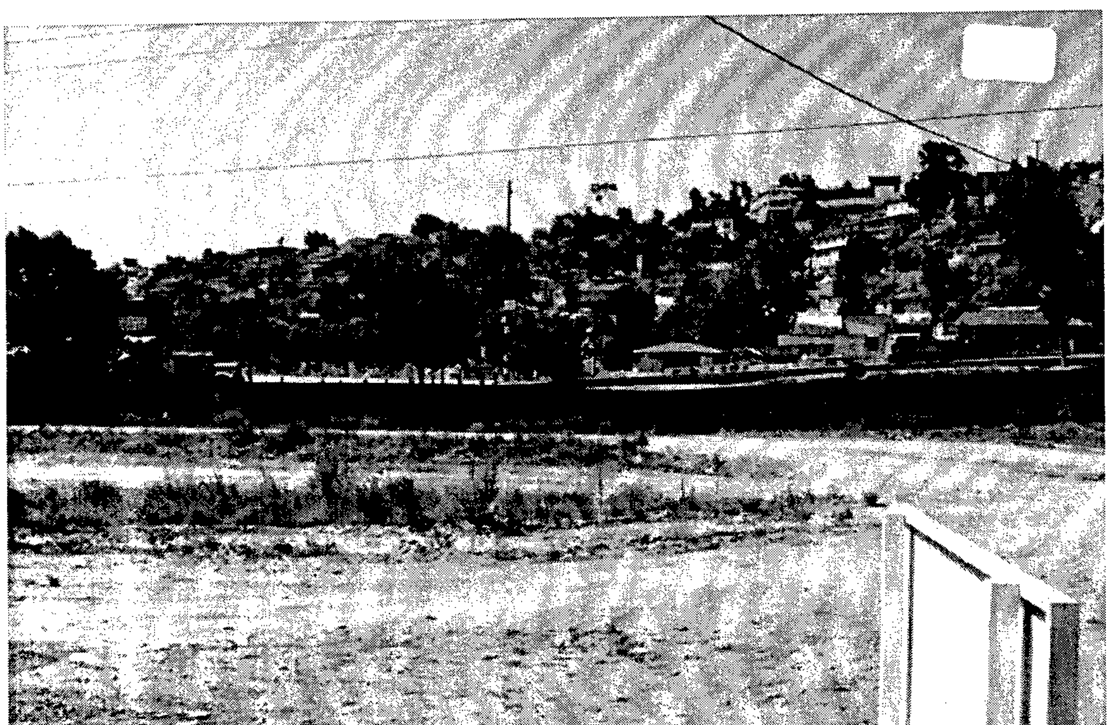

Figure B.15. Flat ground south of the sewage treatment plant.

Section 5 – West of San Ysidro

The Tijuana levee is east of the sewage plant. The fence borders the levee and extends past the old truck entry point to the San Ysidro border entry point. The area shown in Figure B.16 is another high traffic area where the BP has reinforced the fence. Angled extensions have been added to the top of the fence making it well over 10-ft tall. The support poles for the fence are 3.5-in. diameter pipes (not the well casings) that are welded to the mats only at the end of the pipe. The poles are positioned nearly 12-ft apart on center, which is not sufficient to properly support the weight of the landing mat sections. The pole behind the monument is only 2.5 in. in diameter, which is inadequate to support the weight of the fence. The sections are seven panels high, weighing approximately 1,260 lb. The ground along the levee is firm, so poles have a stable footing. The fence extends from the levee monument down a small hill to the old U.S.-Mexico truck entry point shown in Figure B.17. The secondary landing mat fence starts behind the BP vehicle parked in the shade west of the old gate. The fence runs parallel to the primary barrier. Figure B.18 shows the additional deterrents added to the secondary fence, which is six panels high with two panels in the overhang. Two-ft wide sheet metal is attached to the fence about 5-ft above the ground. In addition, the overhang is capped with 6- to 7-in. diameter PVC pipe, which does not allow anyone climbing the fence to grip the top. The secondary fence appears rusted but not damaged.

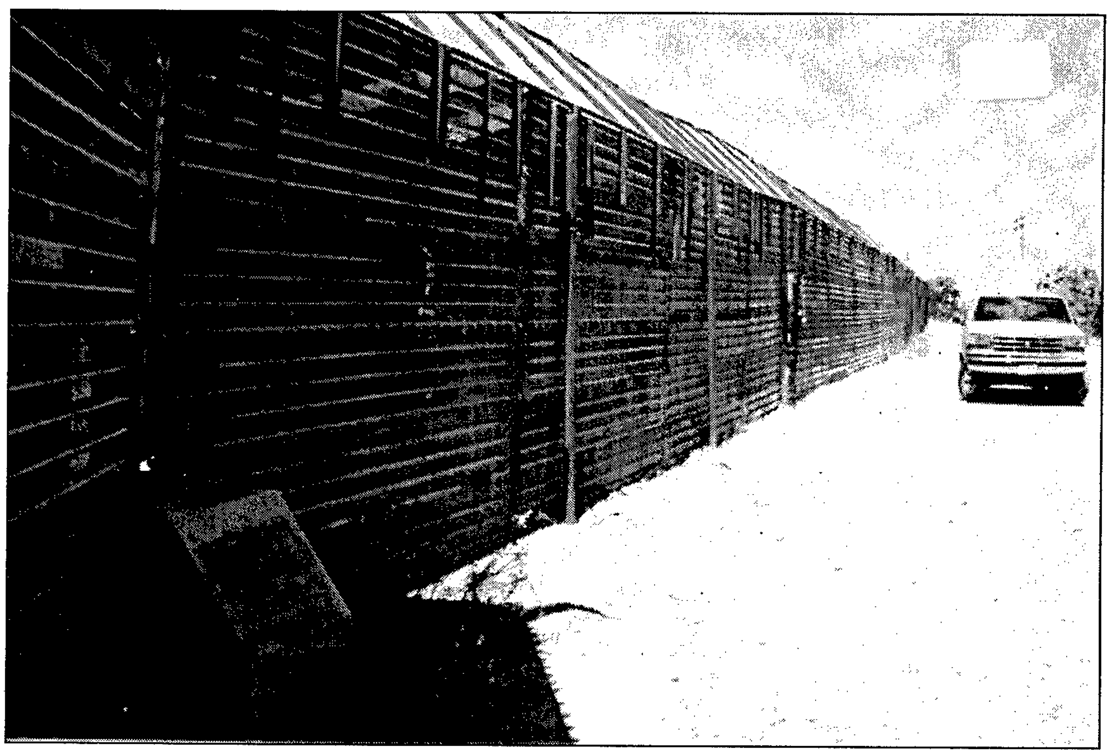

Figure B.16. Fence along the Tijuana levee.

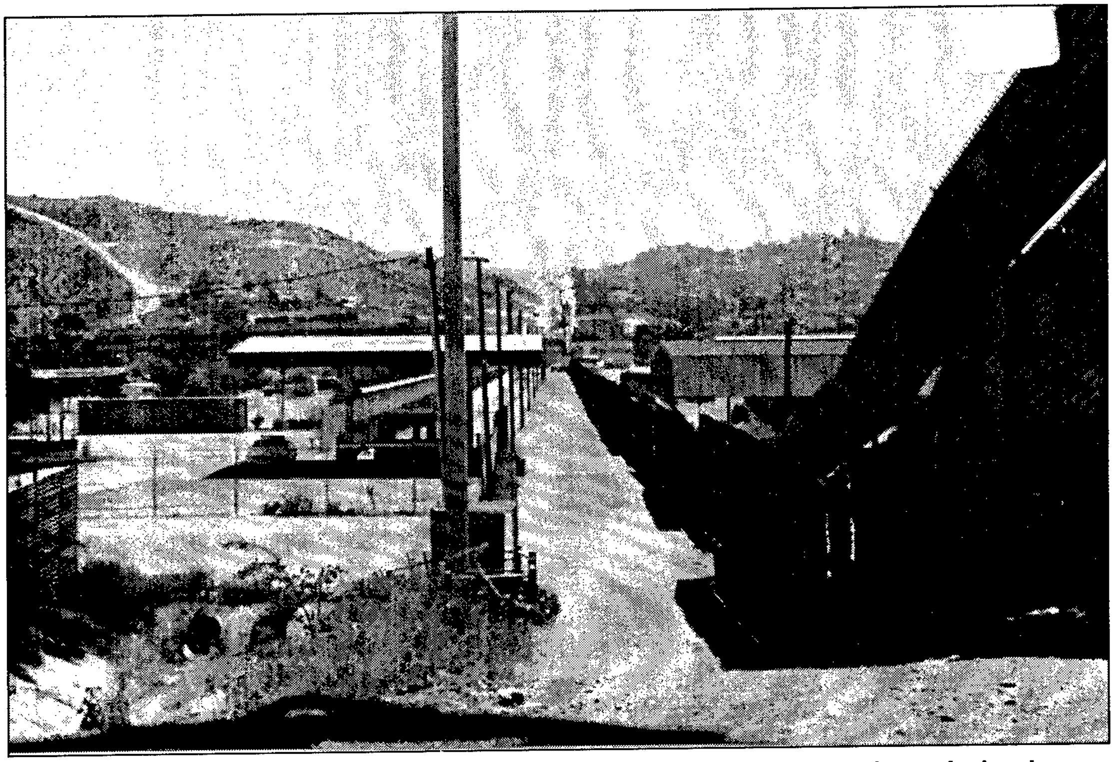

Figure B.17. Fence from the Tijuana levee through the former truck entry point to the border entry point.

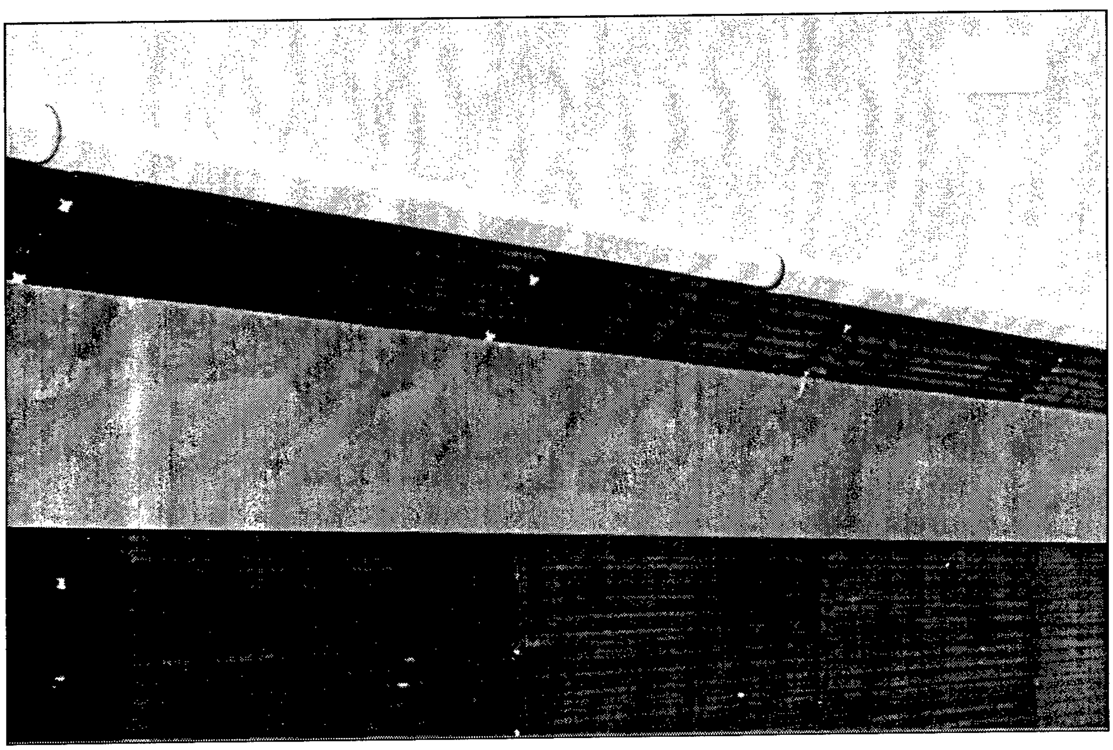

Figure B.18. Secondary fence in the section west of the San Ysidro border entry.

Section 6 – East of San Ysidro

The fence shown in Figure B.19 begins east of the San Ysidro border entry point. The other side of the brown vertical bar fence is Mexican territory. The fence is supported with 2-by-2-in. I-beams embedded in concrete. The concrete reinforcement of the fence bottom with wire mesh inserted into the ground. The I-beams are approximately 10 ft on center and about 8.5-ft aboveground. The deformation in the fence shown in Figure B.19 has resulted from pulling on the fence. The sheared I-beam at the bend indicates that the I-beams are insufficient to support the fence. The panel surfaces have small amounts of corrosion with some of the original paint still intact. The fence extends from the border entry point east to the hilly terrain shown in Figure B.20. Note how close the dwellings on the Mexican side of the fence are to the primary barrier. The hills precede a large stretch of fairly flat ground that is a high traffic area for illegal crossings. The flatness of the ground is shown in Figure B.21. A large highway south of the fence leads to the Tijuana Airport. Figure B.21 shows repairs made to the fence after an accident with a semi-truck on the Mexican highway. The truck bent a section of fence, but the BP was able to bend the damaged pole back to support the panels and maintain the integrity of the fence.

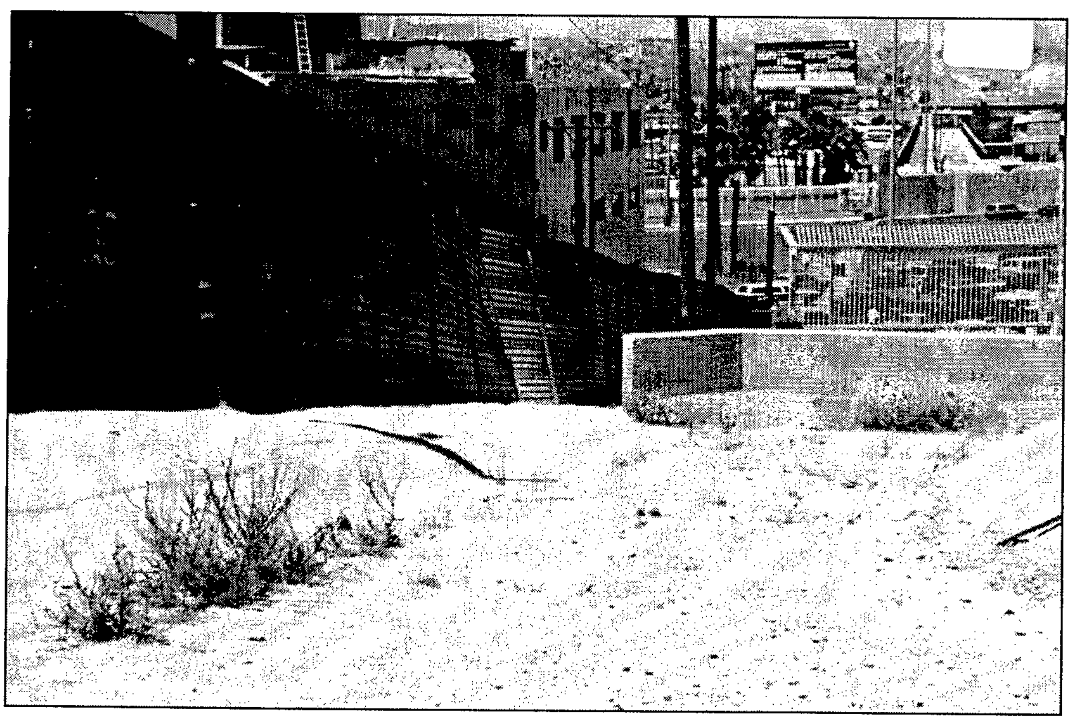

Figure B.19. Fence east of the San Ysidro border entry point.

Figure B.20. Fence extends eastward into hilly terrain.

Figure B.21. Fence running between the hills and the Tijuana Airport is repaired from a truck collision on the Mexican side.

Section 7 – Tijuana Airport to Otay truck border entry

Figure B.22 looks east over the flat landscape preceding the Otay hills in the distance. The soil composition is still loose and sandy, making digging under the fence easy. The 8.5-ft height of the fence makes climbing over the fence easy also. An illegal alien is surveying the ground in the distance. If the BP were to approach him, the alien would just hop back over the fence. The billboards rising above the fence are next to the Tijuana Airport. The chain link fence just 10 to 12 ft north of the primary fence borders private property. The fence has been damaged by heavy traffic, and sections of it are completely gone. Trash from Mexico is also visible. About 1 mile east of the Tijuana Airport and 1 mile west of the Otay truck border entry point is the installation site for the secondary Sandia fence. The Sandia fence is roughly 120 ft north of and parallel to the primary fence.

Figure B.22. Looking east along the fence toward the Otay hills.

Section 8 – east of Otay truck border entry

Figure B.23 shows the fence on the level terrain east of the Otay truck border entry. This area of primary fence has been reinforced at the base with additional landing mat inserted into the ground and concrete. This reinforcement method appears to work very well in preventing dig-under breaches and solidifying the pole supports in the loose soil. There are no major bows in the fence alignment and much of the original paint still exists on the mats. Damage to the fence has been more aggressive in this area of the border. Figure B.24 shows damage to the fence made by cutting and/or disconnecting the panels. Repairs were made by welding a horizontal pipe between vertical supports. The far east part of the fence has not been reinforced with concrete. Figure B.25 shows the result of attacks on this part of the fence by car ramming. The panels toward the top of the fence were separated by the ramming, but the fence did not collapse from the impact. Note that the connections between landing mat sections are welded rods between sections and an additional panel behind the poles without concrete. The sturdiness of the well casings as support poles and the landing mat panel as a primary wall was verified in this incident.

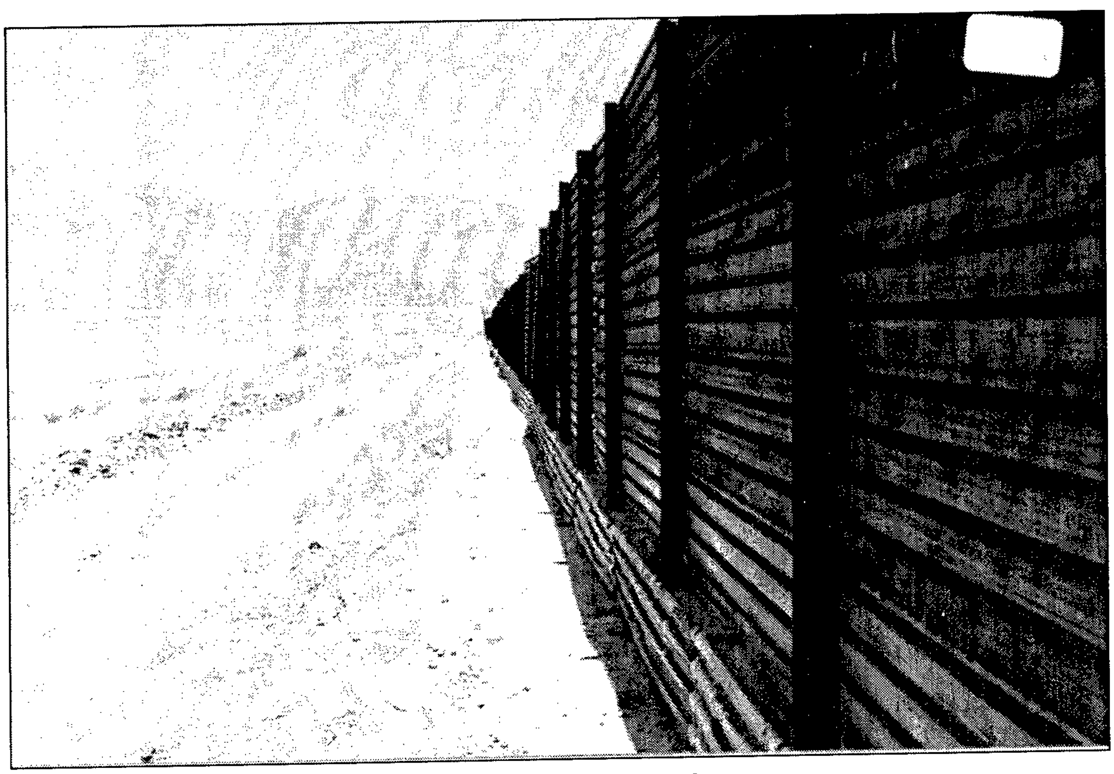

Figure B.23. Flat region of fence east of Otay truck entry point.

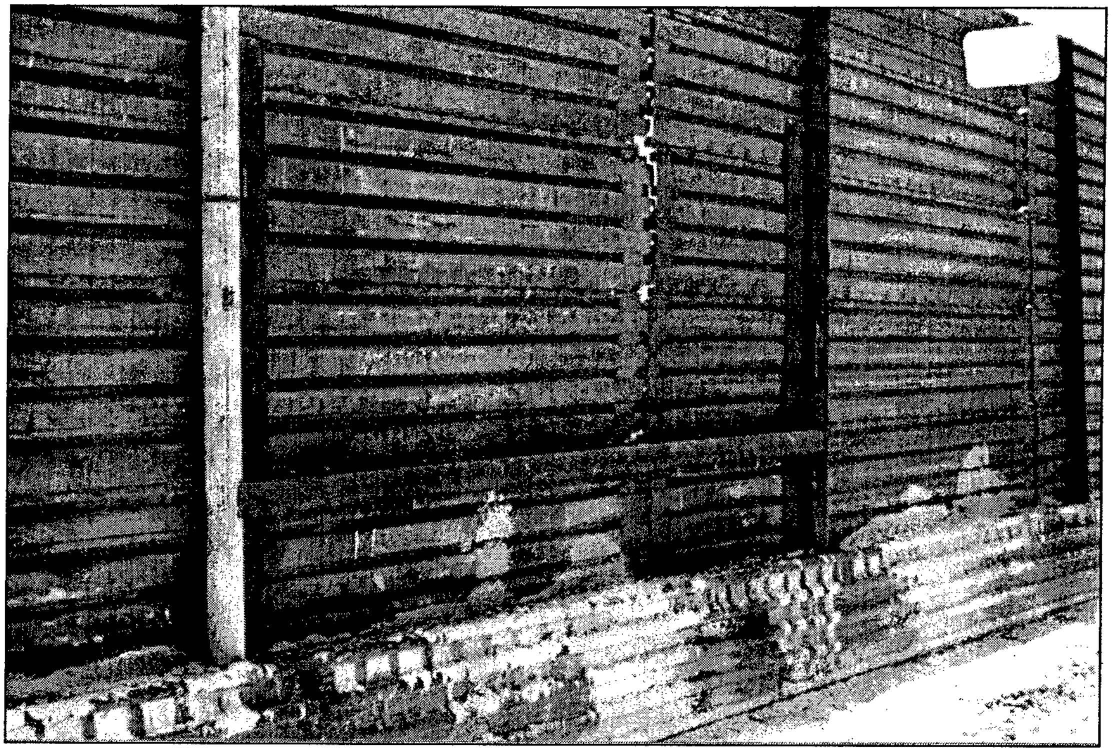

Figure B.24. Repairs to fence damaged by cutting and disassembly.

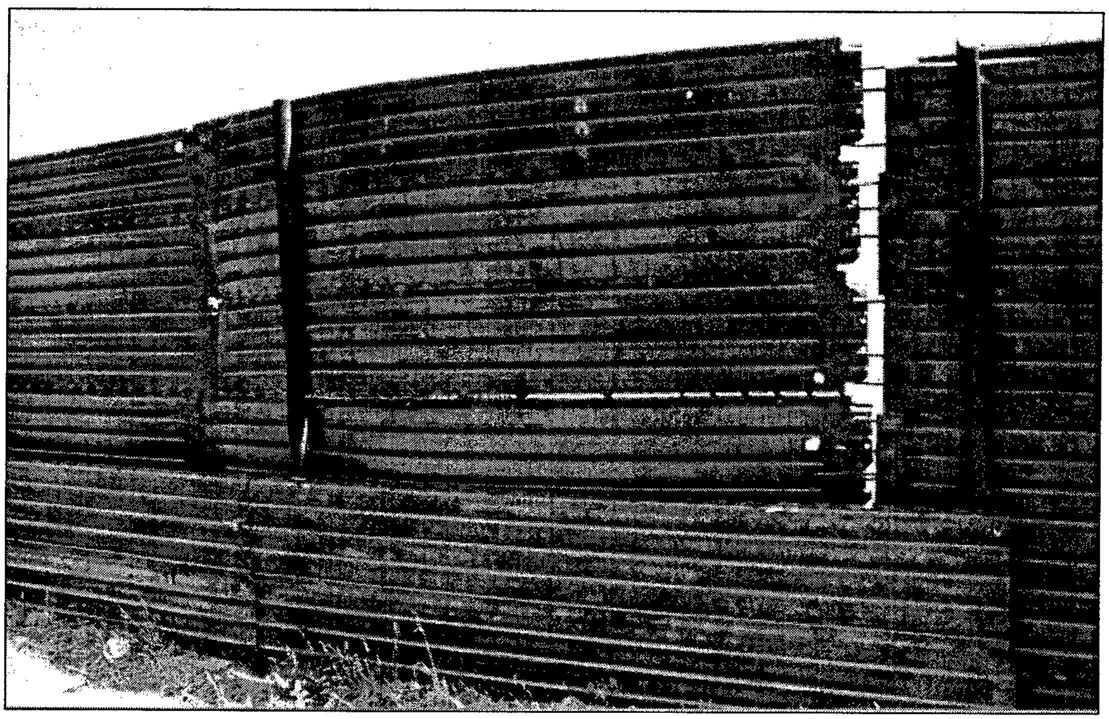

Figure B.25. This fence is still intact after being damaged by car ramming.

Section 9 – Otay hills

The final mile of fence running to the Otay hills is shown in Figure B.26. The hilly terrain makes fence construction difficult. Gaps at the base of the fence (seen in Figure B.27) show the ease with which fence penetration can occur by burrowing under. The loose soil erodes easily from the fence footings. A break between sections is also seen at the bottom of the hill. Figure B.28 shows the end of the fence looking into Mexico. Pathways worn by walking and driving around the fence (at the left of the picture) are visible to onsite inspectors. The inland expansion of Tijuana is shown in the distance.

Figure B.26. The last mile of fence in the Otay hills.

Figure B.27. Gaps exist under the fence, and a break in the section is seen at the bottom of the hill.

Figure B.28. The end of the fence in the Otay hills.

Appendix C: ECONPACK-generated Report for Primary, Secondary, and Tertiary Barriers

Introduction

The purpose of this project was to perform a Life-Cycle Cost Analysis on each barrier option using the software package ECONPACK. For each type of fence, bounding assumptions have been made to attempt to predict the best and worst case scenarios. The following *optimistic* assumptions can be applied to each fence type:

1) Maintenance supplies can be transported to fence without additional cost; terrain is navigable.

2) Active patrol is maintained between the primary and secondary fences; damage by active degradation is negligible beyond the primary barrier.

3) Maintenance work is done rapidly and completely on all fence breaches.

Conversely, the following *pessimistic* assumptions can be applied to each fence type:

1) There is additional cost added to each fence type for transportation because of terrain (a 5% construction cost increase is assumed, with a 2.5% maintenance cost increase).

2) There is no patrol between the primary and secondary fence; the secondary fence in effect becomes the primary barrier, and is hit as hard as the primary barrier in terms of active degradation.

3) Maintenance work is done only in crises situations; breaches of the fence severe enough to allow passage of many individuals or an automobile.

For fences of new construction (bollard and concrete panel), the third year is without maintenance costs (except for stockpiling where necessary). This assumption is based on the fact that during the third year, construction will most likely dominate the activity experienced along the fence (even though the construction period is estimated at two years, there will be holdover activity). This activity, along with Border Patrol presence should minimize active degradation during the third year. In addition to the assumptions listed above, each fence type may have other assumptions made specific to its design. The barrier types and specific assumptions are listed below:

Primary Barrier

Landing Mat.

Optimistic Assumptions: There are no construction costs; only maintenance costs. The maintenance costs consist of repairing 100 acts of degradation per year; 4 drive throughs plus 8 acts per month (8x12=96+4=100). There are no material costs, only labor. Each act of degradation requires 8 man hours. Eight man hours x 100 acts = 800 man hours. Each hour costs $15.00. Total maintenance costs per year equal $12,000.00.

Pessimistic Assumptions: The maintenance costs consist of repairing 300 acts of degradation per year; 12 drive throughs plus 24 acts per month (24x12=288+12=300). The maintenance costs total $36,000.00 annually.

Pre-Cast Concrete Panels.

Optimistic Assumptions: Construction costs total $8,890,000.00 ($630,000.00 per mile x 14 miles). This cost is assumed to be absorbed over the first two years of the project ($5M first year, $3.89M second year) during which time there are no maintenance costs.

Starting with the third year, maintenance costs replace construction costs. The third year's maintenance costs consist of stockpiling extra panels; the entire project uses 6,160 panels, BP should keep ~5% on hand, or 300 panels. Each panel costs $450.00 ($450x300=$135,000.00), the maintenance costs for the third year are $135,000.00. Other than stockpiling, there are no maintenance costs for the third year.

The fourth, fifth, and sixth year's maintenance costs consist of replacing 100 panels (same assumptions as above). The panel cost is zero, but the man hours involved (8 man hours per panel times 100 panels) cost $15.00 per hour; $12,000.00.

The seventh year's maintenance cost will be the re-stockpiling of the panels at $135,000.00 plus the $12,000.00 in labor.

Subsequent years follow suit.

Pessimistic Assumptions: Construction costs total $9,357,895.00 (5% marginal increase because of terrain considerations). This cost is assumed to be absorbed over the first 2 years of the project ($5.26M first year, $4.1M second year) during which time there are no maintenance costs.

Starting with the third year, maintenance costs replace construction costs. The third year's maintenance costs consist of stockpiling 900 panels. Each panel costs $462.00 ($462x900=$415,800.00), the maintenance costs for the third year are $415,800.00. Other than stockpiling, there are no maintenance costs for the third year.

The fourth, fifth, and sixth year's maintenance costs consist of replacing 300 panels. The panel cost is zero, but the man hours involved (8 man hours per panel times 300 panels) cost $15.00 per hour; $36,000.00.

The seventh year's maintenance cost will be the re-stockpiling of the panels at $415,800.00 plus the $36,000.00 in labor.

Subsequent years follow suit.

Bollard Design (Bare Design).

Optimistic Assumptions: Construction costs total $23,338,000 ($1,667,000 per mile x 14 miles). This cost is assumed to be absorbed over the first 2 years of the project ($13.3M first year, $10M second year) during which time there are no maintenance costs.

The third year will have no construction or maintenance costs.

The fourth year's (and beyond) maintenance costs will consist of replacing 120 poles per year (8 acts of active degradation per month plus 4 drive throughs per year, each drive through destroying 6 poles). The cost in material and labor to replace each pole is $500.00. 120x$500=$60,000.00 per year in maintenance costs.

Pessimistic Assumptions: Construction costs total $24,566,316.00. This cost is assumed to be absorbed over the first 2 years of the project ($14M first year, 10.57M second year) during which time there are no maintenance costs.

Fourth year (and beyond) maintenance costs will consist of replacing 360 poles per year (24 acts of degradation per month plus 12 drive throughs per year, each drive through destroying 6 poles). The cost in material and labor to replace each pole is $513.00. 360x$513=$184,680.00 per year in maintenance costs.

Bollard Design (Steel Cased).

Optimistic Assumptions: Construction costs total $29,172,500 ($2,083,750 per mile x 14 miles). The cost is assumed to be absorbed over the first 2 years of the project ($15.5M first year, $13.7M second year) during which time there are no maintenance costs.

The third year will have no construction or maintenance costs.

The fourth year's (and beyond) maintenance costs will consist of replacing 120 poles per year (see above). The cost in material and labor to replace each pole is $625.00. 120x$625=$75,000.00 per year in maintenance costs.

Pessimistic Assumptions: Construction costs total $30,707,895.00. This cost is assumed to be absorbed over the first 2 years of the project ($16.7M first year, 14M second year) during which time there are no maintenance costs.

The fourth year's (and beyond) maintenance costs will consist of replacing 360 poles per year (see above). The cost in material and labor to replace each pole is $641.00. 360x$641=$230,760.00 per year in maintenance costs.

Secondary Barrier

Bollard Design (Bare Design).

Optimistic Assumptions: See above.

Pessimistic Assumptions: See above.

Bollard Design (Steel Cased).

Optimistic Assumptions: See above.

Pessimistic Assumptions: See above.

Sandia Fence.

Optimistic Assumptions: Construction costs total $9,683,520.00. Damage to fence by active degradation is negligible. To offset damage caused by wind/weather, minor maintenance will be required on a periodic basis. The maintenance will be assumed to cost $10,000.00 (10 hours per week (520 hr/yr) billed at $15.00 per man hour = $7,800.00 plus $2,200.00 for supplies) annually.

Pessimistic Assumptions: Construction costs total $10,193,179.00. Damage to fence is severe and unrelenting. Entire fence requires replacement every 2 years because of active degradation.

First DeFence®.

Optimistic Assumptions: Construction costs total $11,679,360.00. Damage to fence by active degradation is negligible. To offset damage caused by wind/weather, minor maintenance will be required on a periodic basis. The maintenance will be assumed to cost $10,000.00 (see above) annually.

Pessimistic Assumptions: Construction costs total $12,294,063.00. Damage to fence is severe and unrelenting. Entire fence requires replacement every 2 years because of active degradation.

Tertiary Barrier

Chain Link Fence (10 ft high).

Optimistic Assumptions: Construction costs total $770,000.00. Damage to fence by active degradation is negligible. To offset damage caused by wind/weather, minor maintenance will be required on a periodic basis. The maintenance will be assumed to cost $5,000.00 (260 hr/yr billed at $15.00 per man hour = $3,900.00 plus $1,100 for supplies) annually.

Pessimistic Assumptions: Construction costs total $810,527.00. Damage to fence is severe and unrelenting. Entire fence requires replacement every two years because of active degradation.

Chain Link Fence (6 ft high).

Optimistic Assumptions: Construction costs total $622,500.00. Damage to fence by active degradation is negligible. To offset damage caused by wind/weather, minor maintenance will be required on a periodic basis. The maintenance will be assumed to cost $5,000.00 (see above) annually.

Pessimistic Assumptions: Construction costs total $655,264.00. Damage to fence is severe and unrelenting. Entire fence requires replacement every two years because of active degradation.

Life Cycle Cost Analysis (ECONPACK)

For the LCCA performed using ECONPACK, the following input parameters were used (as provided by the Corps of Engineers, Ft. Worth, Texas District):

Global Discounting Convention:	Middle-of-year
Period of Analysis:	25 years
Discount Rate:	6.585%
Analysis Type:	Secondary
Cost Input:	Dollars
Report Output Type:	Current
Project Type:	MILCON
Inflation Index:	3.4% flat inflation rate over analysis period

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